(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 October 2003 (16.10.2003)

PCT

(10) International Publication Number
WO 03/085423 A2

(51) International Patent Classification[7]: G02B

(21) International Application Number: PCT/US03/08958

(22) International Filing Date: 21 March 2003 (21.03.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/063,219 29 March 2002 (29.03.2002) US

(71) Applicant *(for all designated States except US)*: **AXE, INC.** [US/US]; 200 MetroWest Technology Drive, Maynard, MA 01754 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **RAO, Hemonth, G.** [US/US]; 50 Beacon Village, Apt. B, Burlington, MA 01803 (US). **HALL, Katherine, L.** [US/US]; 21 Griffin Road, Westford, MA 01886 (US). **LAGASSE, Michael, J.** [US/US]; 28B Muzzy Street, Lexington, MA 02421 (US).

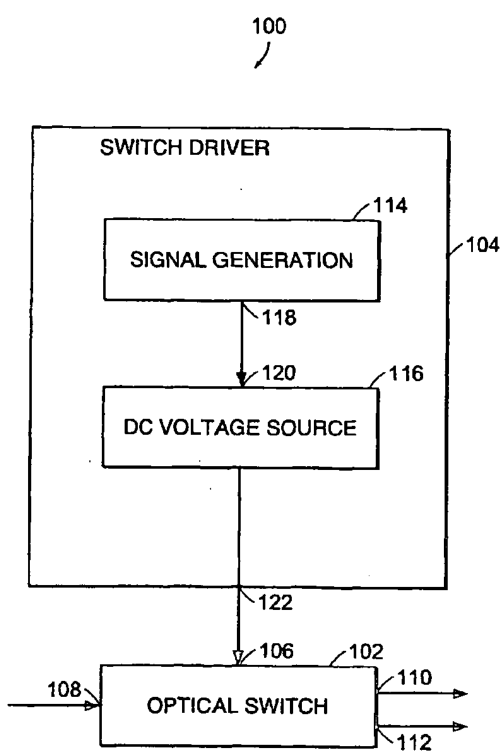
(74) Agent: **RAUSCHENBACH, Kurt**; P.O. Box 387, Bedford, MA 01730 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO,

[Continued on next page]

(54) Title: RECONFIGURABLE TIME-SLOT ROUTER



(57) Abstract: An optical signal router for communication systems is described. The optical signal router includes a switch driver that generates a modulation drive signal containing a linear combination of a DC offset voltage and at least three electrical signals. In one embodiment, each of the at least three electrical signals has a frequency that is a unique integral multiple of a bit-rate. The optical signal router also includes an optical switch having an electrical modulation input that is electrically coupled to the output of the switch driver. The optical switch also includes an optical input that receives a time-division multiplexed optical signal including a plurality of optical subchannels. In one embodiment, each of the plurality of optical subchannels includes the bit-rate. The optical switch routes a subset of the plurality of optical subchannels to an optical output in response to the modulation drive signal.

WO 03/085423 A2

SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Reconfigurable Time-Slot Router

Field of the Invention

[0001] The present invention relates to optical multiplexing and switching in optical communication systems. In particular, the present invention relates to methods and apparatus for performing demultiplexing and switching operations on bit-interleaved optical time-division multiplexed data streams.

Background of the Invention

[0002] Multiplexing techniques are used in optical communication systems to simultaneously transmit many optical data streams along high-bandwidth optical transmission paths. The two principal multiplexing techniques presently used in optical communications systems are optical time-division multiplexing (OTDM) and wavelength-division multiplexing (WDM). OTDM techniques combine lower data-rate optical data signals (optical subchannels) to form a bit-interleaved optical data signal (an OTDM data signal) at a higher data rate. The OTDM data signal has an aggregate bit rate that is the product of a bit-rate of the optical subchannels and the number of multiplexed channels. WDM systems transmit optical data signals along an optical fiber at a number of discrete wavelengths. The optical data signal transmitted at each discrete wavelength may be an OTDM data signal.

[0003] Optical routing techniques, also known as optical switching techniques, are used to direct or to exchange individual optical data channels or groups of optical data channels among interconnected optical communication networks, or between optical communication networks and individual users. For example, individual wavelengths or groups of wavelength can be rapidly and flexibly dropped or added from a WDM optical data signal by using wavelength-selective technologies that leave the remainder of the WDM signal substantially unaffected.

[0004] Similarly effective routing techniques for OTDM data signals would be desirable to enhance the efficiency of optical communication systems. However, known optical routing techniques for dropping and adding optical subchannels or groups of subchannels in OTDM data signals are neither as efficient nor as cost-effective as known WDM routing techniques. An objective for the routing of OTDM data signals in optical communications systems is to rapidly and flexibly select optical subchannels or groups of optical subchannels to be routed, depending on the dynamic requirements of an optical communications system.

[0005] Optical routing in the time domain is currently accomplished either electronically or optically. At lower data rates, electronic routing is fast enough to allow packet-by-packet routing of optical data traffic. However, as data rates increase, this routing method becomes more expensive, uses excessive amounts of electrical power, and requires equipment that is physically large. At data rates higher than a few tens of gigabits per second, electronic routing is generally not utilized and optical routing techniques are usually implemented. Optical cross-connects or mechanical switching suffer less from these limitations, but these switching/routing techniques are relatively slow and can not switch data on a packet-by-packet basis.

[0006] Known OTDM demultiplexers can select alternating optical subchannels from an OTDM data signal using a sinusoidally driven optical switch. That is, a sinusoidal radio-frequency electrical signal, synchronized to the OTDM data signal, is applied to an electrical modulation input of the optical switch. The cascaded application of such sinusoidally-driven optical switches can be used to fully demultiplex an OTDM data signal. A demultiplexer constructed in this manner, however, is complex and relatively inflexible in its operation.

[0007] Under experimental conditions, an electro-absorption switch has been used to select optical pulses at 2.5 gigabits per second (Gb/s) from an optical pulse train having an aggregate bit-rate of forty (40) Gb/s (See, e.g., M.J. Guy, S.V. Chernikov, J.R. Taylor and D.G. Moodie, Electronics Letters, 32, 1139 (1996)). In this experiment, the electro-

optic absorption switch was driven by a combination of two sinusoidal radio-frequency electrical signals operating at different frequencies and a DC offset signal. The experimental result demonstrates the potential to select one optical subchannel from as many as sixteen optical subchannels, at an aggregate bit-rate of up to forty (40) Gb/s.

[0008] However, neither the demonstration of the potential to extract a single optical subchannel nor known OTDM demultiplexers address the need for fully flexible and dynamically reconfigurable routing of optical subchannels of an OTDM data stream.

Summary of the Invention

[0009] The present invention relates to optical devices for routing data signals in a communication system. In one embodiment, the present invention relates to optical signal routers that can select one or more optical subchannels from many optical subchannels of a data stream. An optical signal router according to the present invention can select one or more optical subchannels from many optical subchannels while providing significant flexibility. In one embodiment, the optical signal router is dynamically re-configurable to provide substantially real-time routing of the optical subchannels.

[0010] Accordingly, in one aspect, the invention is embodied in an optical signal router. The optical signal router includes a switch driver that generates at an output a modulation drive signal including a linear combination of a DC offset voltage and at least three electrical signals. In one embodiment, each of the at least three electrical signals has a frequency that is a unique integral multiple of a bit-rate. In another embodiment, at least one of the at least three electrical signals is generated by at least one of a plurality of electrical signal generators. In another embodiment, a signal combiner combines the at least three electrical signals to generate the modulation drive signal.

[0011] In one embodiment, the optical signal router also includes an adjustable DC voltage source that generates the DC offset voltage. In another embodiment, the switch driver is adapted so that at least one of an amplitude and a phase of at least one of the at

least three electrical signals is adjustable. In another embodiment, a number of the at least three electrical signals is less than a number of optical subchannels. In yet another embodiment, a frequency of each of the least three electrical signals is lower than an aggregate bit rate of the time-division multiplexed optical signal.

[0012] The optical signal router also includes an optical switch having an electrical modulation input that is electrically coupled to the output of the switch driver. The optical switch includes an optical input that receives a time-division multiplexed optical signal including a plurality of optical subchannels. Each of the plurality of optical subchannels propagates at the bit-rate.

[0013] In one embodiment, the optical switch routes a subset of the plurality of optical subchannels to an optical output of the optical switch in response to the modulation drive signal. In another embodiment, the optical switch routes the subset of the plurality of optical subchannels to the optical output of the optical switch in response to at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals.

[0014] In one embodiment, the optical switch includes an interferometric switch. In another embodiment, the optical switch includes a Mach-Zehnder interferometric switch. In yet another embodiment, the optical switch comprises a polarization-insensitive optical switch. In still another embodiment, the optical switch includes an optical absorption switch.

[0015] In another embodiment, the optical signal router also includes an optical signal generator that generates the time-division multiplexed optical signal comprising a plurality of optical subchannels. In alternate embodiments, the optical signal generator generates a polarization-multiplexed, time-division multiplexed optical signal, a wavelength-division multiplexed, time-division multiplexed optical signal or at least one of a wavelength-division multiplexed, time-division multiplexed, or polarization-multiplexed optical signal.

[0016] In one embodiment, an aggregate bit rate of the time-division multiplexed optical signal is equal to or greater than ten gigabits per second. In another embodiment, an aggregate bit rate of the time-division multiplexed optical signal is equal to or greater than eighty gigabits per second. In one embodiment, the plurality of optical subchannels includes at least four optical subchannels. In another embodiment, the plurality of optical subchannels includes at least eight optical subchannels.

[0017] In another aspect, the invention is embodied in a method for routing optical signals. The method includes receiving a time-division multiplexed optical signal including a plurality of optical subchannels. Each of the plurality of optical subchannels has a bit-rate. In one embodiment, an aggregate bit rate of the time-division multiplexed optical signal is at least ten gigabits per second. In another embodiment, an aggregate bit rate of the time-division multiplexed optical signal is at least eighty gigabits per second. In another embodiment, the plurality of optical subchannels includes at least four optical subchannels. In yet another embodiment, the plurality of optical subchannels includes at least eight optical subchannels.

[0018] The method further includes generating a modulation drive signal that selects a subset of the plurality of optical subchannels. In one embodiment, the modulation drive signal includes a linear combination of a DC offset voltage and at least three electrical signals. In another embodiment, each of the at least three electrical signals has a frequency that is a unique integral multiple of the bit-rate. In one embodiment, generating the modulation drive signal that selects a subset of the plurality of optical subchannels includes varying at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals. In another embodiment, the number of the at least three electrical signals is less than the number of optical subchannels. In yet another embodiment, a frequency of each of the at least three electrical signals is lower than an aggregate bit rate of the time-division multiplexed optical signal.

[0019] In one embodiment, selecting the subset of the plurality of optical signals

includes routing the subset of the plurality of optical signals along a first optical path and routing a complementary subset of the plurality of optical subchannels along a second optical path. In another embodiment, selecting the subset of the plurality of optical signals includes routing the subset of the plurality of optical signals along an optical path and dropping a complementary subset of the plurality of optical subchannels.

[0020] In one embodiment, the method further includes selecting another subset of the plurality of optical subchannels by changing at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals.

[0021] In one embodiment, selecting the subset of the plurality of optical subchannels is performed within one microsecond. In another embodiment, selecting the subset of the plurality of optical subchannels is performed within ten nanoseconds.

[0022] The method further includes modulating the time-division multiplexed optical signal including the plurality of optical subchannels with the modulation drive signal, thereby selecting the subset of the plurality of optical subchannels. In one embodiment, the method further includes generating the time-division multiplexed optical signal comprising a plurality of optical subchannels.

[0023] In one embodiment, the time-division multiplexed optical signal having a plurality of optical subchannels includes a polarization-multiplexed time-division multiplexed optical signal. In another embodiment, the time-division multiplexed optical signal having a plurality of optical subchannels includes a wavelength-division multiplexed time-division multiplexed optical signal. In yet another embodiment, the time-division multiplexed optical signal having a plurality of optical subchannels includes at least one of a wavelength-division multiplexed, time-division multiplexed, and polarization-multiplexed optical signal.

Brief Description of the Drawings

[0024] This invention is described with particularity in the appended claims. The above and further advantages of this invention may be better understood by referring to the following description in conjunction with the accompanying drawings, in which like numerals indicate like structural elements and features in various figures. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0025] FIG. 1 illustrates a block diagram of an optical signal router according to the present invention.

[0026] FIG. 2 illustrates a block diagram of an optical signal router that includes a 1x1 optical switch according to the present invention.

[0027] FIG. 3 illustrates tables of configurations of the 1x1 optical signal router of FIG. 2 according to the present invention.

[0028] FIG. 4 illustrates a block diagram of an optical signal router that includes a 1x2 optical switch according to the present invention.

[0029] FIG. 5 illustrates tables of configurations of the 1x2 optical signal router of FIG. 4 according to the present invention.

[0030] FIGS. 6A-6D illustrate normalized drive voltage waveforms for routing various optical subchannels to an optical output of a 1x2 optical switch according to the present invention.

[0031] FIGS. 7A-7D illustrate normalized drive voltage waveforms for routing various optical subchannels to an optical output of a 1x2 optical switch according to the present invention.

[0032] FIGS. 8A-8D illustrate normalized drive voltage waveforms for routing various

optical subchannels to an optical output of a 1x2 optical switch according to the present invention.

[0033] FIGS. 9A and 9B illustrate normalized drive voltage waveforms for routing various optical subchannels to an optical output of a 1x2 optical switch according to the present invention.

[0034] FIGS. 10A and 10B illustrate normalized drive voltage waveforms for routing all or none, respectively, of the optical subchannels to an optical output of a 1x2 optical switch according to the present invention.

[0035] FIG. 11 illustrates a functional diagram of a 1x2 optical signal router according to the present invention.

[0036] FIG. 12 illustrates a functional diagram of a 1x2 optical signal router having independent outputs according to the present invention.

[0037] FIG. 13 illustrates a block diagram of a 1xM optical signal router according to the present invention.

[0038] FIG. 14 illustrates a block diagram of a cascaded optical signal router according to the present invention.

[0039] FIG. 15 illustrates a block diagram of an optical add-drop multiplexer according to the present invention.

[0040] FIG. 16 illustrates a block diagram of an MxM optical cross connect according to the present invention

Detailed Description

[0041] Referring more particularly to the figures, FIG. 1 illustrates a block diagram of an optical signal router 100 according to the present invention. The optical signal router 100 includes an optical switch 102 and a switch driver 104. The optical switch 102 is a

one-by-two (1x2) optical switch that includes an optical input 108 and two optical outputs 110, 112. In one embodiment, the 1x2 optical switch 102 is an optical modulator. In other embodiments, LxM optical switches (not shown) can be designed using multiple optical modulators in cascaded configurations.

[0042] The 1x2 optical switch 102 receives a time-division multiplexed data signal (a TDM data signal) at the optical input 108. In one embodiment, the TDM data signal is optically time-division multiplexed (an OTDM data signal). The OTDM data signal includes N optical subchannels, where N is an integer. Each of the N optical subchannels is an optical data stream having a subchannel bit-rate B, measured in units of gigabits per second (Gb/s). In one embodiment, the N optical subchannels are spaced substantially evenly in time.

[0043] The OTDM data signal has an aggregate bit-rate R that is equal to the sum of the subchannel bit-rate B of each of the N optical subchannels. That is, the aggregate bit-rate R is equal to the product of the subchannel bit-rate B and N, the number of optical subchannels. The aggregate bit-rate R can be any bit-rate that is supported by a switching speed of the 1x2 optical switch 102 and that is within a frequency-generating range of the switch driver 104.

[0044] In one embodiment, the OTDM data signal has an aggregate bit-rate R of forty (40) Gb/s and includes four optical subchannels, each of the four optical subchannels having a subchannel bit-rate B of ten (10) Gb/s. In another embodiment, the OTDM data signal has an aggregate bit-rate R of eighty (80) Gb/s and includes eight optical subchannels, each of the eight optical subchannels having a subchannel bit-rate B of ten (10) Gb/s. In yet another embodiment, the OTDM data signal has an aggregate bit-rate R of one hundred and sixty (160) Gb/s and includes sixteen optical subchannels, each of the sixteen optical subchannels having a subchannel bit-rate B of ten (10) Gb/s.

[0045] The switch driver 104 includes an adjustable waveform generator 114 that performs signal generation and a DC voltage source 116. The switch driver 104

generates a switch driver signal at a switch driver output 122. The optical switch 102 receives the switch driver signal at an electrical input 106.

[0046] The adjustable waveform generator 114 generates a composite electrical signal that includes at least three time-varying electrical signals at an electrical output 118. Each of the at least three electrical signals is characterized by a frequency, an amplitude, and a phase. In one embodiment, the frequency of each of the at least three electrical signals is a unique integral multiple of the subchannel bit-rate B of the OTDM data signal that includes N optical subchannels.

[0047] In one embodiment, the adjustable waveform generator 114 generates a composite electrical signal that includes a first, a second, and a third time-varying electrical signal. The first time-varying electrical signal has a frequency that is equal to the subchannel bit rate B. The second time-varying electrical signal has a frequency that is equal to twice the subchannel bit rate B. The third time-varying electrical signal has a frequency that is equal to three times the subchannel bit rate B.

[0048] In another embodiment, the adjustable waveform generator 114 generates more than three time-varying electrical signals having frequencies following the sequence B, 2B, 3B,...., through N-1 times the subchannel bit rate B.

[0049] The DC voltage source 116 is electrically coupled to the electrical output 118 of the adjustable waveform generator 114 and receives the composite electrical signal at an electrical input 120. The DC voltage source 116 introduces an adjustable DC offset voltage to the composite electrical signal, thereby generating the driver signal at the switch driver output 122. The switch driver output 122 is electrically coupled to the electrical input 106 of the optical switch 102. The driver signal, at least in part, determines the behavior of the optical signal router 100.

[0050] The behavior of the optical signal router 100 is configured by adjusting at least one of the DC offset voltage, a phase of at least one of the at least three electrical signals, and an amplitude of at least one of the at least three time-varying electrical signals. Thus,

adjusting a waveform of the driver signal modifies the behavior of the optical signal router 100. In one embodiment, the waveform of the driver signal is time dependent.

[0051] In one embodiment, the DC offset voltage and at least one of the phase and the amplitude of at least one of the at least three time-varying electrical signals are independently adjustable. In one embodiment, the adjusting of the waveform of the driver signal is completed within a time that is substantially equal to a time required to reconfigure the optical signal router 100 (the reconfiguration time).

[0052] In one embodiment the at least three time-varying electrical signals includes N-1 time-varying electrical signals. In this embodiment, the optical signal router 100 can be configured to have any of a total of 2^N configurations. In one embodiment, a maximum frequency of any one of the N-1 time-varying electrical signals is equal to N-1 times the subchannel bit-rate B, or (N-1)/N times the aggregate bit-rate R of the OTDM data signal. This maximum frequency is lower than the aggregate bit-rate R of the OTDM data signal.

[0053] In one embodiment, this lower maximum frequency facilitates the development of higher data-rate optical communication networks using optical switches that have limited switching speeds. In one embodiment, the 1x2 optical switch 102 includes narrow-band electrodes that optimize its switching speed and reduce the voltage required to drive the switch.

[0054] In one embodiment, the adjustable waveform generator 114 includes one electrical signal generator (not shown) that generates the composite electrical signal that includes at least three time-varying electrical signals. In one embodiment, the electrical signal generator is a radio-frequency harmonic amplifier.

[0055] In another embodiment, the adjustable waveform generator 114 includes at least two electrical signal generators (not shown). Each of the at least two electrical signal generators generates at least one of the at least three time-varying electrical signals. In this embodiment, the adjustable waveform generator 114 also includes an electrical

power combiner (not shown) that electrically combines the time-varying electrical signals generated by the at least two electrical signal generators, thereby generating the composite electrical signal at the electrical output 118.

[0056] In yet another embodiment, at least one of the at least two electrical signal generators is a narrow-band radio-frequency signal generator. In still another embodiment, at least one of the at least two electrical signal generators is a radio-frequency harmonic amplifier.

[0057] In operation, the optical switch 102 receives the OTDM data signal including N optical subchannels at the optical input 108. A subset of the N optical subchannels (a subset) is a distinct combinatorial subgrouping of the N optical subchannels. For each subset, all of the N optical subchannels that are not included in the subset define a complementary subset of the N optical subchannels (a complementary subset). For example, if an OTDM data signal includes a first and a second optical subchannel, and a first subset includes only the first optical subchannel, then a first complementary subset would include only the second optical subchannel.

[0058] There are a total of 2^N subsets of an OTDM data signal that include N optical subchannels. The number 2^N denotes two raised to the N^{th} power. In one embodiment, the OTDM data signal includes four optical subchannels, and thus the total number of subsets is 2^4 subsets, or sixteen subsets. In another embodiment, the OTDM data signal includes sixteen optical subchannels, and thus the total number of subsets is 2^{16} subsets, or 65,536 subsets.

[0059] In one embodiment, the optical signal router 100 routes one of a plurality of subsets from the optical input 108 to an optical output 110 of the 1x2 optical switch 102. In alternative embodiments, the maximum number of subsets in the plurality of subsets can be equal to a total of 2^N subsets, or can be a smaller number of subsets. A selection of one of the plurality of subsets to be routed from the optical input 108 to the optical output 110 of the optical switch 102 is determined by the switch driver signal.

[0060] The one subset in the plurality of subsets that is selected is dependent on the configuration of the optical signal router 100. The configuration of the optical signal router 100 is determined, at least in part, by the driver signal. The plurality of subsets thus corresponds to a plurality of configurations of the optical signal router 100, thus the total number of 2^N subsets corresponds to a total number of 2^N configurations of the optical signal router 100.

[0061] The selection of different ones of the plurality of subsets can be achieved by adjusting the switch driver signal. That is, the optical signal router 100 can be reconfigured by adjusting of the switch driver signal. The optical signal router 100 is reconfigurable and, therefore, is referred to herein as a reconfigurable optical signal router 100.

[0062] For example, the optical signal router 100 can route a first one of the plurality of subsets (a first subset) from the optical input 108 to the optical output 110 of the optical switch 102. This selection of the first subset represents a first configuration of the optical signal router 100. The optical signal router 100 can be reconfigured to route a second one of the plurality of subsets (a second subset) from the optical input 108 to the optical output 110 of the optical switch 102. This selection of the second subset represents a second configuration of the optical signal router 100.

[0063] The time required to reconfigure the optical signal router 100 from the first configuration to the second configuration is referred to as the reconfiguration time. A short reconfiguration time is desirable to maximize the optical data throughput of an optical communication system. The minimum value of the reconfiguration time is limited by the response speed of the 1x2 optical switch 102 and by the speed with which the switch driver 104 can complete an adjustment of the switch driver signal. In one embodiment, depending on the response speed of the 1x2 optical switch 102, the value of the reconfiguration time is less than one microsecond. In another embodiment, depending on the response speed of the 1x2 optical switch 102, the value of the reconfiguration time is approximately one nanosecond. Skilled artisans will appreciate

that the response speed of the switch is limited by the switch technology.

[0064] In another embodiment, the 1x2 optical switch 102 routes a first subset of N optical subchannels of the OTDM data signal from the optical input 108 to the optical output 110. In another embodiment, the first complementary subset is routed to a second optical output 112. The selection of the first subset routed from the optical input 108 to the optical output 110 is determined by a drive signal received at the electrical input 106. The optical switch 102 can be any type of 1x2 optical switch. In one embodiment, the optical switch 102 is a 1x2 interferometric switch. In another embodiment, the 1x2 interferometric switch is a Mach-Zehnder interferometric switch.

[0065] The 1x2 optical switch 102 routes a subset of N optical subchannels to a first optical output 110 or to a second optical output 112. The selection of the first optical output 110 or the second optical output 112 of the 1x2 optical switch 102 is determined by a driver signal received at the electrical input 106 of the 1x2 optical switch. In one embodiment, the 1x2 optical switch 102 routes a subset of a plurality of optical subchannels of an OTDM data signal to the first optical output 110 and routes the complementary subset to the second optical output 112.

[0066] A one-by-one (1x1) optical switch (not shown) is an optical switch that has one optical input (an optical input) and one optical output. In an “on state,” the 1x1 optical switch routes an optical signal that is received at the optical input to the one optical output. In an “off state,” the 1x1 optical switch does not route the optical signal from the optical input to the one optical output. The selection of an “on” or an “off state” of the 1x1 optical switch is determined by a driver signal that is received at a modulation input of the 1x1 optical switch.

[0067] In one embodiment, a subset of a plurality of N optical subchannels of an OTDM data signal that is not routed from the optical input to the one optical output of the 1x1 optical switch is said to be dropped. In another embodiment, a complementary subset of the N optical channels that is not routed from the optical input to the optical

output is also dropped. For example, in an OTDM data signal having a first and second optical subchannel, a 1x1 optical switch that routes a first subset that includes only the first optical subchannel to an optical output, drops the first complementary subset that includes only the second optical subchannel.

[0068] In one embodiment, the 1x1 optical switch routes one of a plurality of subsets of optical subchannels of an OTDM data signal from the optical input to the optical output and drops the complementary subset. The selection of the subset that is routed from the optical input to the optical output is determined by a drive signal that is received at an electrical input (not shown) to the 1x1 optical switch. The optical switch can be any type of 1x1 optical switch. In one embodiment, the 1x1 optical switch is an electro-absorption switch.

[0069] An optical signal router 100 of the present invention can be used to route an OTDM data signal that is also a wavelength-division multiplexed (WDM) data signal. Wavelength-division multiplexing increases the bandwidth of an optical communication system by simultaneously transmitting optical data signals at multiple wavelengths along an optical fiber. For example, the optical signal router 100 of the present invention can route an optical subchannel of an OTDM data signal that is also a WDM data signal to an optical communications device that performs wavelength-demultiplexing of the optical subchannel. In another embodiment, the optical signal router 100 of the present invention can route a data signal to an optical communications device that performs wavelength-multiplexing of the data signal.

[0070] In another embodiment, the optical signal router 100 of the present invention can be used to route an OTDM data signal that is a polarization-multiplexed data signal. Polarization-division multiplexing increases the bandwidth of an optical communication system by transmitting optical data signals having orthogonal polarizations along an optical fiber. For example, the optical signal router 100 of the present invention can route an optical subchannel of an OTDM data signal that is also a polarization-multiplexed data signal to an optical communications device that performs polarization-

demultiplexing of the optical subchannel. In another example, the optical signal router 100 of the present invention can route a data signal to an optical communications device that performs polarization-multiplexing of the data signal.

[0071] In yet another embodiment, the optical signal router 100 of the present invention can be used to route an OTDM data signal that is both a WDM data signal and a polarization-multiplexed data signal. For example, the optical signal router 100 of the present invention can route an optical subchannel of an OTDM data signal that is a polarization-multiplexed WDM data signal to an optical communications device that performs both polarization and wavelength-demultiplexing of the optical subchannel. In another embodiment, the optical signal router 100 of the present invention can route an optical subchannel of an OTDM data signal that is a polarization-multiplexed WDM data signal to an optical communications device that performs both polarization and wavelength-multiplexing of the optical subchannel.

[0072] FIG. 2 illustrates a functional block diagram a 1x1 optical signal router 150 according to the present invention. The 1x1 optical signal router 150 includes a 1x1 optical switch 152. The 1x1 optical switch 152 includes an optical input 154 and an optical output 156. The 1x1 optical switch 152 also includes an electrical input 158 that receives a switch driver signal from a switch driver 160. In one embodiment, the 1x1 optical switch 152 is an electro-absorption switch.

[0073] In one embodiment, the 1x1 optical switch 152 receives an OTDM data signal that includes four optical subchannels at the optical input 154. The OTDM data signal can be divided into a total of 2^4 or sixteen subsets of the four optical subchannels. Thus, the 1x1 optical signal router 152 has a total of sixteen configurations. In one embodiment, the OTDM data signal has an aggregate bit-rate R of substantially forty (40) Gb/s and each of the four optical subchannels has a subchannel bit-rate B of substantially ten (10) Gb/s.

[0074] The switch driver signal determines which one of the sixteen subsets of the four

optical subchannels is routed from the optical input 154 to the optical output 156 of the 1x1 optical switch 152. That is, the switch driver signal determines one of the sixteen configurations of the 1x1 optical signal router 150. In one embodiment, the switch driver 160 includes an adjustable waveform generator 162 and a DC voltage source 164. The adjustable waveform generator 162 generates a composite electrical signal that includes three time-varying electrical signals at an electrical output 166.

[0075] In one embodiment, the adjustable waveform generator 162 includes a first signal generator 168 that generates a first time-varying electrical signal having a frequency f_1. In one embodiment, the frequency f_1 is substantially ten (10) gigahertz (GHz). A first phase modulator 170 adjusts the phase of the first time-varying electrical signal. At least one of a first amplifier 172 and a first attenuator 174 adjusts the amplitude of the first time-varying electrical signal.

[0076] The adjustable waveform generator 162 also includes a second signal generator 176 that generates a second time-varying electrical signal having a frequency f_2. In one embodiment, the frequency f_2 is substantially twenty (20) gigahertz (GHz). In another embodiment, the frequency f_2 is an integer multiple of the frequency f_1. A second phase modulator 178 adjusts the phase of the second time-varying electrical signal. At least one of a second amplifier 180 and a second attenuator 182 adjusts the amplitude of the second time-varying electrical signal.

[0077] The adjustable waveform generator 162 further includes a third signal generator 184 that generates a third time-varying electrical signal having a frequency f_3. In one embodiment, the frequency f_3 is substantially thirty (30) gigahertz (GHz). In another embodiment, the frequency f_3 is an integer multiple of the frequency f_1. A third phase modulator 186 adjusts the phase of the third time-varying electrical signal. At least one of a third amplifier 188 and a third attenuator 190 adjusts the amplitude of the third time-varying electrical signal.

[0078] The adjustable waveform generator 162 also includes a signal combiner 192.

The signal combiner 192 is adapted to combine the first, second and third time-varying optical signals into a composite electrical signal. The signal combiner 192 outputs the composite electrical signal to an electrical output 166 of the adjustable waveform generator 162.

[0079] The DC voltage source 164 is electrically coupled to the electrical output 166 of the adjustable waveform generator 162 at an electrical input 194. The DC voltage source 164 adds an adjustable DC offset voltage to the composite electrical signal, thereby generating the driver signal. A switch driver output 196 receives the driver signal. The switch driver output 196 is electrically coupled to an electrical input 158 of the 1x1 optical switch 152.

[0080] In one embodiment, the 1x1 optical signal router 150 is configured by adjusting at least one of the first 170, the second 178, and the third 186 phase modulator; the first 172, the second 180, and the third 188 amplifier; the first 174, the second 182, and the third 190 attenuator; and the DC voltage source 164. In another embodiment, the 1x1 optical signal router 150 is configured by adjusting an appropriate combination of the first 170, the second 178, and the third 186 phase modulator; the first 172, the second 180, and the third 188 amplifier; the first 174, the second 182, and the third 190 attenuator; and the DC voltage source 164.

[0081] In another embodiment, the 1x1 optical signal router 150 is configured by adjusting at least one of the adjustable DC offset voltage, a phase of at least one of the three time-varying electrical signals, and an amplitude of at least one of the three time-varying electrical signals. Thus, the 1x1 optical signal router 150 is configured by adjusting a waveform of the driver signal.

[0082] In one embodiment, the reconfiguration time of the 1x1 optical signal router is determined by a response speed of the 1x1 optical switch 152. In another embodiment, the reconfiguration time of the 1x1 optical signal router 150 is determined by the speed with which the switch driver 160 can complete an adjustment of the drive voltage

waveform. In one embodiment, the reconfiguration time is less than one microsecond. In another embodiment, the reconfiguration time is approximately one nanosecond.

[0083] FIG. 3 illustrates tables of configurations 198 of the 1x1 optical signal router 150 of FIG. 2 according to the present invention. In the table of 1x1 switching configurations 198, the four optical subchannels 200 are labeled as optical subchannel 1, 2, 3, and 4.

[0084] A first table 202 illustrates each of the sixteen configurations of the 1x1 optical signal router 150. The configurations of the 1x1 optical signal router 150 are grouped vertically in the first table 202, based on the number of optical subchannels being routed from the optical input 154 to the optical output 156.

[0085] A second table 204 illustrates the respective optical subchannels that are dropped for each of the sixteen configurations of the 1x1 optical signal router 150. Each row of the second table 204 represents a complementary subset to the subset of the four optical subchannels illustrated in the corresponding row in the first table 202.

[0086] In alternate embodiments, the design principles of the 1x1 optical signal router 150 previously discussed can be utilized to construct a 1x1 optical signal router having a larger number of configurations than the sixteen configurations of the 1x1 optical signal router 150. For example, in one embodiment, the adjustable waveform generator 162 generates a composite electrical signal that includes three time-varying electrical signals and the OTDM data signal includes sixteen optical subchannels, corresponding to a total of 65,536 unique configurations. In alternative embodiments, the adjustable waveform generator 162 can generate a composite electrical signal that includes more than three time-varying electrical signals (not shown).

[0087] FIG. 4 illustrates a functional diagram of a 1x2 optical signal router 206 according to the present invention. The 1x2 optical signal router 206 includes a 1x2 optical switch 208. The 1x2 optical signal router 206 includes similar components to the 1x1 optical signal router 150 described with reference to FIG. 2. Specifically, the 1x2

optical signal router 206 includes the switch driver 160 and a 1x2 optical switch 208. In one embodiment, the 1x2 optical switch 208 is an interferometric switch. In another embodiment, the interferometric switch is a Mach-Zehnder interferometric switch.

[0088] In one embodiment, the 1x2 optical switch 208 receives an OTDM data signal that includes four optical subchannels at an optical input 210. There are a total of sixteen subsets of the four optical subchannels. Thus, the 1x2 optical signal router 206 can have a total of sixteen configurations. In one embodiment, the OTDM data signal has an aggregate bit-rate R of forty (40) Gb/s and each of the four optical subchannels has a substantially identical subchannel bit-rate B of ten (10) Gb/s.

[0089] The 1x2 optical signal router 206 includes the switch driver 160. The switch driver 160 generates a driver signal at the switch driver output 196. The 1x2 optical switch 208 receives the driver signal at an electrical input 212. The switch driver signal determines which one of the sixteen subsets of the four optical subchannels is routed by the 1x2 optical switch 208 from the optical input 210 to a first optical output 214. The 1x2 optical signal router 206 is configured by adjusting a waveform of the driver signal.

[0090] The 1x2 optical switch 208 routes a complementary one of the sixteen subsets to a second optical output 216. The first optical output 214 of the 1x2 optical switch 208 is labeled output A and the second optical output is labeled output B in FIG. 4.

[0091] In one embodiment, the reconfiguration time of the 1x2 optical signal router 206 is determined by the response speed of the 1x2 optical switch 208. In another embodiment, the reconfiguration time of the 1x2 optical signal router 206 is determined by the speed with which the switch driver 160 can complete an adjustment of the drive voltage waveform. In one embodiment, the reconfiguration time is less than one microsecond depending on the response speed of the 1x2 optical switch 208. In another embodiment, the reconfiguration time is approximately one nanosecond depending on the response speed of the 1x2 optical switch 208.

[0092] FIG. 5 illustrates tables of configurations 218 of the 1x2 optical signal router

206 of FIG. 4 according to the present invention. In the table of 1x2 switching configurations 218, the four optical subchannels 220 are labeled as optical subchannel 1, 2, 3, and 4.

[0093] A first table 222 illustrates each of the sixteen configurations of the 1x2 optical signal router 206. The configurations of the 1x2 optical signal router 206 are grouped vertically in the first table 222, based on the number of optical subchannels being routed from the optical input 210 to the first optical output 214. The first optical output 214 is labeled OUTPUT A in FIG. 4.

[0094] A second table 224 illustrates the optical subchannels that are routed from the optical input 210 to the second optical output 216. Each row of the second table 224 represents a complementary subset to the subset of the four optical subchannels illustrated in the corresponding row in the first table 222.

[0095] In alternate embodiments, the design principles of the 1x2 optical signal router 206 previously discussed can be utilized to construct a 1x2 optical signal router having a larger number of configurations than the sixteen configurations of the 1x2 optical signal router 206. For example, in one embodiment, the adjustable waveform generator 162 generates a composite electrical signal that includes three time-varying electrical signals and the OTDM data signal includes sixteen optical subchannels, corresponding to a total of 65,536 unique configurations. In alternative embodiments, the adjustable waveform generator 162 can generate a composite electrical signal that includes more than three time-varying electrical signals (not shown).

[0096] The switch driver signal determines a selection of one of the sixteen configurations of the 1x2 optical signal router 206. The driver signal has a unique waveform for each of the sixteen configurations of the 1x2 optical signal router 206. FIG. 6A through Fig 10B illustrate various waveforms of the driver signal for each one of the sixteen configurations of the 1x2 optical signal router 206.

[0097] FIG. 6A through FIG. 10B illustrate the time dependence of a normalized drive

voltage having a voltage amplitude range of approximately –1 to approximately +1 volt (a normalized drive voltage waveform) for the various waveforms of the driver signal. In one embodiment, an optical switch used in an optical time router according to the present invention requires a driver signal having a voltage amplitude range that is consistent with voltage requirements of the optical switch. In one embodiment, the 1x2 optical switch 208 requires a driver signal having a voltage amplitude range of approximately zero to approximately 5 volts.

[0098] The time scale of the horizontal axis of the graphs in FIG. 6A through FIG. 10B is in units of bit periods. A bit-period is defined as the time between consecutive optical pulses of the OTDM data signal that includes the four optical subchannels being received at the optical input 210 of the optical switch 208 (the OTDM data signal). This time scale results in each graph being independent of the aggregate bit-rate R of the OTDM data signal.

[0099] FIG. 6A through FIG. 10B illustrate various positions in time of the four optical subchannels of the OTDM data signal relative to the drive voltage waveform. The four optical subchannels are represented as four pulses in each graph, each pulse being centered within a bit-period. Pulses representing each of the four optical subchannels are labeled 1, 2, 3, and 4, respectively, in FIG. 6A through 10B. The vertical extent and the time width of the pulses representing the four optical subchannels are arbitrarily scaled in FIG. 6A through FIG. 10B.

[0100] FIG. 6A is a graphical illustration 250 of a normalized drive voltage waveform 252 for configuring the 1x2 optical signal router 206 to route the second, third, and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first optical subchannel 254 is routed to the second optical output 216 of the 1x2 optical switch 208. The graph 250 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 252.

[0101] FIG. 6B is a graphical illustration 256 of a normalized drive voltage waveform 258 for configuring the 1x2 optical signal router 206 to route the first, third, and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining second optical subchannel 254 is routed to the second optical output 216 of the 1x2 optical switch 208. The graph 256 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 258.

[0102] FIG. 6C is a graphical illustration 260 of a normalized drive voltage waveform 262 for configuring the 1x2 optical signal router 206 to route the first, second, and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining third optical subchannel 254 is routed to the second optical output 216 of the 1x2 optical switch 208. The graph 260 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 262.

[0103] FIG. 6D is a graphical illustration 264 of a normalized drive voltage waveform 266 for configuring the 1x2 optical signal router 206 to route the first, second, and third optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining fourth optical subchannel 254 is routed to the second optical output 216 of the 1x2 optical switch 208. The graph 264 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 266.

[0104] FIG. 7A is a graphical illustration 268 of a normalized drive voltage waveform 270 for configuring the 1x2 optical signal router 206 to route the first optical subchannel 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining second, third, and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 268 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 270.

[0105] FIG. 7B is a graphical illustration 272 of a normalized drive voltage waveform 274 for configuring the 1x2 optical signal router 206 to route the second optical subchannel 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first, third, and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 272 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 274.

[0106] FIG. 7C is a graphical illustration 276 of a normalized drive voltage waveform 278 for configuring the 1x2 optical signal router 206 to route the third optical subchannel 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first, second, and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 276 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 278.

[0107] FIG. 7D is a graphical illustration 280 of a normalized drive voltage waveform 282 for configuring the 1x2 optical signal router 206 to route the fourth optical subchannel 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first, second, and third optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 280 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 282.

[0108] FIG. 8A is a graphical illustration 284 of a normalized drive voltage waveform 286 for configuring the 1x2 optical signal router 206 to route the third and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first and second optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 284 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 286.

[0109] FIG. 8B is a graphical illustration 288 of a normalized drive voltage waveform 290 for configuring the 1x2 optical signal router 206 to route the first and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining second and third optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 288 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 290.

[0110] FIG. 8C is a graphical illustration 292 of a normalized drive voltage waveform 294 for configuring the 1x2 optical signal router 206 to route the first and second optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining third and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 292 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 294.

[0111] FIG. 8D is a graphical illustration 296 of a normalized drive voltage waveform 298 for configuring the 1x2 optical signal router 206 to route the second and third optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 296 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 298.

[0112] FIG. 9A is a graphical illustration 300 of a normalized drive voltage waveform 302 for configuring the 1x2 optical signal router 206 to route the second and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining first and third optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 300 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 302.

[0113] FIG. 9B is a graphical illustration 304 of a normalized drive voltage waveform 306 for configuring the 1x2 optical signal router 206 to route the first and third optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The remaining second and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 304 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 306.

[0114] FIG. 10A is a graphical illustration 308 of a normalized drive voltage waveform 310 for configuring the 1x2 optical signal router 206 to route the first, second, third, and fourth optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. None of the four optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 308 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 310.

[0115] FIG. 10B is a graphical illustration 312 of a normalized drive voltage waveform 314 for configuring the 1x2 optical signal router 206 to route none of four optical subchannels 254 from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. The first, second, third, and fourth optical subchannels 254 are routed to the second optical output 216 of the 1x2 optical switch 208. The graph 312 also illustrates the positions in time of the four optical subchannels 254 relative to the normalized drive voltage waveform 314.

[0116] In one embodiment, a normalized drive voltage waveform $v_1(t)$ of a driver signal that routes three of the four optical subchannels from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208 can be expressed by the formula:

$$v_1(t) = \frac{2}{i+2j+k}\{i\cos(\omega_0 t+\phi)+j[\cos(2\omega_0 t+\phi)-1]+k\cos(3\omega_0 t+\phi)\}$$

where ω_0 is 2π times the subchannel bit-rate B, where t is time, and where i=1.00, j=0.66,

and k=0.31. In one embodiment, the subchannel bit-rate B is substantially ten (10) Gb/s. The remaining one of the four optical subchannels that is not routed to the first optical output 214 of the 1x2 optical switch 208 is routed to the second optical output 216 of the optical switch 208. The drive voltage waveforms 252, 258, 262, and 266 illustrated in FIG. 6A through 6D, respectively, are representative of the drive voltage waveform $v_1(t)$.

[0117] Additionally, ϕ represents the phase of the waveform. The phase of the waveform determines which of the four optical subchannels is routed from the optical input 210 to the second optical output 216 of the 1x2 optical switch 208. For example, phase values equal to $-\pi/4$, $-3\pi/4$, $3\pi/4$, and $\pi/4$ correspond to the first, the second, the third, and the fourth of the four optical subchannels, respectively, being routed to the second optical output 216 of the 1x2 optical switch 208.

[0118] In one embodiment, a normalized drive voltage waveform $v_2(t)$ of a driver signal that routes one of the four optical subchannels from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208 can be expressed by the formula:

$$v_2(t) = \frac{-2}{i+2j+k}\{i\cos(\omega_0 t+\phi)+j[\cos(2\omega_0 t+\phi)-1]+k\cos(3\omega_0 t+\phi)\}$$

where ω_0 is 2π times the subchannel bit-rate B, where t is time, and where i=1.00, j=0.66, and k=0.31. In one embodiment, the subchannel bit-rate B is substantially ten (10) Gb/s. The remaining three of the four optical subchannels that is not routed to the first optical output 214 of the 1x2 optical switch 208 is routed to the second optical output 216 of the optical switch 208. The drive voltage waveforms 270, 274, 278, and 282 illustrated in FIG. 7A through 7D, respectively, are representative of the drive voltage waveform $v_2(t)$.

[0119] Additionally, ϕ represents the phase of the waveform. The phase of the waveform determines which of the four optical subchannels is routed from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. For example, phase values equal to $-\pi/4$, $-3\pi/4$, $3\pi/4$, and $\pi/4$ correspond to the first, the second, the

third, and the fourth of the four optical subchannels, respectively, being routed to the first optical output 214 of the 1x2 optical switch 208.

[0120] In one embodiment, a normalized drive voltage waveform $v_3(t)$ of a driver signal that routes two adjacent optical subchannels of the four optical subchannels from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208 can be expressed by the formula:

$$v_3(t) = \sin(\omega_0 t + \phi) + 0.4\sin(3\omega_0 t + 3\phi)$$

where ω_0 is 2π times the subchannel bit-rate B and where t is time. In one embodiment, the subchannel bit-rate B is substantially ten (10) Gb/s. The two of the four optical subchannels that are not routed to the first optical output 214 of the 1x2 optical switch 208 are routed to the second optical output 216 of the optical switch 208. The drive voltage waveforms 286, 290, 294, and 298 illustrated in FIG. 8A through 8D, respectively, are representative of the drive voltage waveform $v_3(t)$.

[0121] Additionally, ϕ represents the phase of the waveform. The phase of the waveform determines which two adjacent optical subchannels of the four optical subchannels is routed from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. For example, a phase value equal to π corresponds to the first and the second of the four optical subchannels being routed to the first optical output 214 of the 1x2 optical switch 208.

[0122] In one embodiment, a normalized drive voltage waveform $v_4(t)$ of a driver signal that routes two non-adjacent optical subchannels of the four optical subchannels from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208 can be expressed by the formula:

$$v_4(t) = \sin(2\omega_0 t + \phi)$$

where ω_0 is 2π times the subchannel bit-rate B and where t is time. In one embodiment,

the subchannel bit-rate B is substantially ten (10) Gb/s. The two non-adjacent optical subchannels that are not routed to the first optical output 214 of the 1x2 optical switch 208 are routed to the second optical output 216 of the optical switch 208. The drive voltage waveforms 302 and 306 illustrated in FIG. 9A and FIG. 9B, respectively, are representative of the drive voltage waveform $v_4(t)$.

[0123] Additionally, ϕ represents the phase of the waveform. The phase of the waveform determines which two non-adjacent optical subchannels of the four optical subchannels are routed from the optical input 210 to the first optical output 214 of the 1x2 optical switch 208. For example, a phase value equal to zero corresponds to the second and fourth of the four optical subchannels being routed to the first optical output 214 of the 1x2 optical switch 208.

[0124] A driver signal having a drive voltage waveform that is a constant voltage routes all of the four optical subchannels from the optical input 210 to either the first optical output 214 or the second optical output 216 of the 1x2 optical switch 208, depending on the amplitude of the voltage. Normalized drive voltage waveforms 310 and 314 having a constant voltage are illustrated in FIG. 10A and FIG. 10B.

[0125] As described above, FIG. 6A through FIG. 10B illustrate drive voltage waveforms for the 1x2 optical signal router 206. FIG. 6A through FIG. 10B can also be used to illustrate drive voltage waveforms for the 1x1 optical signal router 150. The 1x1 optical switch 152 includes the optical output 156 and does not include a second optical output. For the 1x1 optical signal router 150, an optical subchannel that is not routed to the optical output 156 is dropped.

[0126] FIG. 11 illustrates an embodiment of a 1x2 optical signal router 350 according to the present invention. In one embodiment, the 1x2 optical signal router 350 includes a 1x2 optical switch (not shown). The 1x2 optical signal router 350 has an optical input 352, a first optical output 354, and a second optical output 356. An optical input of an optical signal router 350 according to the present invention is the optical input of the 1x2

optical switch of the optical signal router 350. An optical output of an optical signal router is the optical output of the 1x2 optical switch of the optical signal router 350.

[0127] The 1x2 optical signal router 350 receives an OTDM data signal having a plurality of optical subchannels 358 at the optical input 352. The 1x2 optical signal router 350 routes a subset 360 of the plurality of optical subchannels 358 from the optical input 352 to the first optical output 354. The 1x2 optical signal router 350 routes a complementary subset 362 to the subset 360 of the plurality of optical subchannels 350 to the second optical output 356.

[0128] The 1x2 optical signal router 350 can be characterized as having complementary outputs 354, 356. That is, a selection of the subset 360 of the plurality of optical subchannels that is routed to the first optical output 354 also selects the complementary subset 362 that is routed to the second optical output 356. In one embodiment, the plurality of optical subchannels includes four optical subchannels. In another embodiment, the subset of the plurality of optical subchannels includes three of the four optical subchannels, and the complementary subset includes one of the four optical subchannels. In yet another embodiment, the subset of the plurality of optical subchannels includes two of the four optical subchannels, and the complementary subset includes two of the four optical subchannels. In still another embodiment, the subset of the plurality of optical subchannels includes one of the four optical subchannels, and the complementary subset includes three of the four optical subchannels.

[0129] FIG. 12 illustrates an embodiment of a 1x2 optical signal router 364 having independent outputs 382, 384 according to the present invention. The 1x2 optical signal router 364 having independent outputs 382, 384 includes a first 1x1 optical signal router 366 and a second 1x1 optical signal router 368. Each of the first 366 and the second 1x1 optical signal router 368 includes a 1x1 optical switch (not shown).

[0130] The 1x2 optical signal router 364 having independent outputs 382, 384 also includes an optical splitter 370 that splits an OTDM data signal having a plurality of

optical subchannels 372 into a first and a second substantially equivalent OTDM data signal. The first 1x1 optical signal router 366 receives the first substantially equivalent OTDM data signal at an optical input 374. The second 1x1 optical signal router 368 receives the second substantially equivalent OTDM data signal at an optical input 376.

[0131] The first 1x1 optical signal router 366 routes a first subset 378 of the plurality of optical subchannels 372 from the optical input 374 to a first optical output 382. The second 1x1 optical signal router 368 routes a second subset 380 of the plurality of optical subchannels 372 from the optical input 376 to a second optical output 384. A selection of the first subset 378 of the plurality of optical subchannels 372 can be made independently of a selection of the second subset 380 of the plurality of optical subchannels 372.

[0132] In one embodiment, the second subset 380 of the plurality of optical subchannels 372 is identical to the first subset 378 of the plurality of optical subchannels 372. In another embodiment, the second subset 380 of the plurality of optical subchannels 372 is a complementary subset to the first subset 378 of the plurality of optical subchannels 372. In yet another embodiment, the second subset 380 of the plurality of optical subchannels 372 is independent of the first subset 378 of the plurality of optical subchannels 372.

[0133] In one embodiment, the plurality of optical subchannels 372 includes four optical subchannels. In another embodiment, the first subset 378 of the four optical subchannels includes three optical subchannels and the second subset 380 of the four optical subchannels is a complementary subset to the first subset 378 and includes one of the four optical subchannels.

[0134] The 1x2 optical signal router 350 having complementary outputs 354, 356 of FIG. 11 and the 1x2 optical signal router 364 having independent outputs 382, 384 of FIG. 12 illustrate two alternative approaches to constructing a 1x2 optical signal router according to the present invention. The 1x2 optical signal router 364 having independent outputs 382, 384 is relatively flexible. The 1x2 optical signal router 350 having

complementary outputs 354, 356 is relatively easy to construct and includes fewer components.

[0135] In one embodiment, the optical splitter 370, is a polarization dependent optical splitter (not shown) which performs polarization demultiplexing of the optical subchannels 372. In this embodiment, a first subset of optical subchannels (e.g., subchannels 1 and 3) corresponding to one polarization state is routed by the polarization dependent optical splitter to the optical input 374, while a second subset of optical subchannels (e.g., subchannels 2 and 4) corresponding to another polarization state is routed by the polarization dependent optical splitter to the optical input 376. In another embodiment, the polarization states are orthogonal to each other.

[0136] FIG. 13 illustrates an embodiment of a 1xM optical signal router 400 according to the present invention. The 1xM optical signal router 400 is an optical signal router having one optical signal router input 402 and M optical signal router outputs 404, where M is an integer that is greater than one. The 1x2 optical signal router 364 having independent outputs 382, 384 of FIG. 12 is a 1xM optical signal router with M equal to two.

[0137] The 1xM optical signal router 400 includes a 1xM optical splitter 406 and M 1x1 optical signal routers 408. The 1xM optical splitter 406 receives at the optical signal router input 402 an OTDM data signal that includes N optical subchannels. The 1xM optical splitter 406 splits the OTDM data signal that includes N optical subchannels into M substantially equivalent OTDM data signals.

[0138] Each of the M substantially equivalent OTDM data signals is generated at each of a respective M optical splitter outputs 410. Each of the M optical splitter outputs 410 is optically coupled to a respective optical input 412 of each one of the M 1x1 optical signal routers 408. Each of the M 1x1 optical signal routers 408 routes a subset of the N optical subchannels to a respective one of the M optical signal router outputs 404.

[0139] The 1xM optical signal router 400 can be configured to route any subset of the

N optical subchannels to any of the M optical signal router outputs 404. In one embodiment, the 1xM optical signal router 400 routes a unique subset of the N optical subchannels to each of the M optical signal router outputs 404. In another embodiment, the number of the M optical signal router outputs 404 is equal to the number of optical subchannels. That is, M is equal to N. In another embodiment, M is greater than N. In yet another embodiment, M is less than N. In one embodiment, M is equal to four and the 1xM optical signal router 400 has four optical signal router outputs 404. In another embodiment, M is equal to sixteen and the 1xM optical signal router 400 has sixteen optical signal router outputs 404.

[0140] FIG. 14 illustrates an embodiment of a cascaded optical signal router 450 according to the present invention. The cascaded optical signal router 450 includes a first 1x2 optical signal router 452 having an optical input 454, a first optical output 456, and a second optical output 458. The first optical output 456 of the first optical signal router 452 is optically coupled to an optical input 460 of a second 1x2 optical signal router 462. The second optical output 458 of the first optical signal router 452 is optically coupled to an optical input 464 of a third 1x2 optical signal router 466.

[0141] The second 1x2 optical signal router 462 includes a first optical output 468 and a second optical output 470. The third 1x2 optical signal router 466 includes a first optical output 472 and a second optical output 474. The first 1x2 optical signal router 452 is a first stage of the cascaded optical signal router 450. The second 1x2 optical signal router 462 and the third 1x2 optical signal router 466 together comprise a second stage of the cascaded optical signal router 450.

[0142] In other embodiments, additional stages of 1x2 optical signal routers (not shown) can be added to the cascaded optical signal router 450. In one embodiment, each optical output from a 1x2 optical signal router in one stage is optically coupled to an optical input of a 1x2 optical signal router in the added stage. Each added stage of 1x2 optical signal routers includes twice the number of 1x2 optical signal routers as the preceding stage. Each added stage of 1x2 optical signal routers also doubles the number

of optical outputs of the cascaded optical signal router, relative to the previous stage. In one embodiment, a cascaded optical signal router includes four stages, has sixteen optical outputs, and includes a total of fifteen 1x2 optical signal routers. In alternative embodiments, combinations of 1x1 optical signal routers and 1x2 optical signal routers can be cascaded to create numerous cascaded optical signal router configurations.

[0143] The cascaded optical signal router 450 receives an OTDM data signal at the optical input 454 of the first 1x2 optical signal router 452. The cascaded optical signal router 450 can be configured such that any subset of N optical subchannels can be routed from the optical input 454 to any of the cascaded optical signal router outputs 468, 470, 472, and 474. In one embodiment, the number of optical outputs of the cascaded optical signal router 450 is equal to the number of the N optical subchannels. In another embodiment, the number of optical outputs of the cascaded optical signal router 450 is greater than the number of the N optical subchannels. In yet another embodiment, the number of optical outputs of the cascaded optical signal router 450 is less than the number of the N optical subchannels.

[0144] FIG. 15 illustrates an embodiment of an optical add-drop multiplexer 500 according to the present invention. The optical add-drop multiplexer 500 includes a 1xM optical signal router 502 having an optical multiplexer input 504 and M optical router outputs 506. The optical add-drop multiplexer 500 also includes an optical combiner 508 having M optical combiner inputs 510 and an optical combiner output 512. The optical add-drop multiplexer 500 also includes M-1 routing interfaces 514. Each of the M-1 routing interfaces 514 is coupled to a communication system 516. In one embodiment, the M-1 routing interfaces 514 are electronic routing interfaces. In another embodiment, the communication system 516 is an electronic communication system.

[0145] In one embodiment, the 1xM optical signal router 502 receives an OTDM data signal including N optical subchannels at the optical multiplexer input 504. In one embodiment, the OTDM data signal is a 40Gb/s data signal. In other embodiments, the OTDM data signal is an 80Gb/s or a 160Gb/s data signal. The 1xM optical signal router

502 routes a subset of the N optical subchannels from the optical multiplexer input 504 to each of the M optical router outputs 506. In one embodiment, each of the N optical subchannels has a subchannel bit-rate in the range of 0Gb/s to 40Gb/s. In one embodiment, a subset of the N optical subchannels is independently determined for each of the M optical router outputs 506. A first one of the M optical router outputs 506 is optically coupled to a respective first one of the optical combiner inputs 510. The optical combiner inputs 510 receive a first subset of the N optical subchannels.

[0146] Each of the second through the M^{th} of the M optical router outputs 506 is optically coupled to a respective optical interface input 518 of one of the M-1 routing interfaces 514. Each of the M-1 routing interfaces 514 converts the subset of the N optical subchannels received from the 1xM optical signal router 502 to a data signal. The data signal is coupled to the communication system 516. In one embodiment, the subset of the N optical subchannels routed to each of the second through the M^{th} optical router outputs 506 includes one of the N optical subchannels.

[0147] Each of the M-1 routing interfaces 514 receives a return data signal from the communication system 516, and generates a return optical data signal at respective optical interface outputs 520. The return optical data signal includes at least one optical subchannel that is synchronized with the OTDM data signal. In one embodiment, the synchronization between the at least one optical channel and the OTDM data signal can be done in the communication system 516 or in each of the M-1 routing interfaces 514.

[0148] The optical interface outputs 520 of each of the M-1 routing interfaces 514 is optically coupled to a respective one of the M optical combiner inputs 510. The optical combiner 508 generates a multiplexer output optical signal at the optical combiner output 512. The multiplexer output optical signal is a combination of the first subset of the N optical subchannels and the return optical data signal generated at the interface optical output 520 of each of the M-1 routing interfaces 514. In one embodiment, the return optical data signal has a bit-rate in the range of 0Gb/s to 40Gb/s. In one embodiment, each of the N optical subchannels has a subchannel bit-rate in the range of 0Gb/s to

40Gb/s.

[0149] In one embodiment, the optical add-drop multiplexer 500 performs optically all of the switching functions required to add or drop optical subchannels of the OTDM optical data signal including N optical subchannels. In one embodiment, the optical add-drop multiplexer 500 routes a variable number of optical subchannels to the M-1 routing interfaces 514. In other embodiments, this routing depends on changes in the OTDM data signal and/or on variations in data traffic.

[0150] In one embodiment, the OTDM data signal routed by the optical add-drop multiplexer 500 is also a WDM optical data signal. In one embodiment, the OTDM data signal routed by the optical add-drop multiplexer 500 is also a polarization-division multiplexed optical data signal. In one embodiment, M is equal to four and the optical add-drop multiplexer 500 includes three routing interfaces 514. In another embodiment, M is equal to sixteen and the add-drop multiplexer 500 includes fifteen routing interfaces 514.

[0151] FIG. 16 illustrates an embodiment of an LxM optical cross connect 550 according to the present invention. The LxM optical cross-connect 550 includes a plurality of 1xM optical signal routers 552. Each of the plurality of 1xM optical signal routers 552 includes M optical router outputs 554 and an optical router input 556. Each of the plurality of 1xM optical signal routers 552 receives one of a plurality of OTDM data signals having a plurality of optical subchannels.

[0152] The LxM optical cross-connect also includes a plurality of optical combiners 558. Each of the plurality of optical combiners 558 includes a plurality of optical combiner inputs 560 and one optical combiner output 562. In the embodiment illustrated in FIG. 16, both L and M are equal to four. That is, the LxM optical cross-connect 550 includes four 1x4 optical signal routers 552 and four optical combiners 558. In one embodiment, each of the four optical combiners 558 includes four optical combiner inputs 560. In another embodiment, both L and M are equal to sixteen (not shown). In

one embodiment, the LxM optical cross-connect 550 includes four 1x16 optical signal routers 552 and sixteen optical combiners 558. Each of the sixteen optical combiners 558 includes sixteen optical combiner inputs 560.

[0153] One of the M optical router outputs 554 of each of the plurality of 1xM optical signal routers 552 is optically coupled to one of the M optical combiner inputs 560 of each of the M optical combiners 558. Each of the plurality of 1xM optical signal routers 552 can route an independently selected subset of the plurality of optical subchannels of one of the plurality of OTDM data signals to each of the M optical combiners 558.

[0154] The LxM optical cross-connect 550 requires synchronization among the optical subchannels that are combined by the M optical combiners 558. The synchronization can be achieved by remotely synchronizing the plurality of OTDM data signals received by the plurality of 1xM optical signal routers 552. The synchronization can also be achieved locally by adding adjustable optical delays (not shown) between the plurality 1xM optical signal routers 552 and the M optical combiners 558.

[0155] The LxM optical cross connect 550 can also be modified to include an optical add-drop multiplexer constructed in the manner of the add-drop optical multiplexer 500 of FIG. 15. The LxM optical cross-connect 550 can be used for mesh networks in optical communication systems. The LxM optical cross-connect 550 can also be used for joining bi-directional optical fiber rings in optical communication systems.

[0156] Any of the embodiments of optical signal routers discussed herein can be constructed as an assembly of discrete optical and optoelectronic devices. Any of the embodiments of optical signal routers discussed herein can also be constructed as integrated devices using integrated optical techniques. For example, a 1xM optical signal router can be built using a discrete optical splitter and M discrete 1x1 optical signal routers, each of the M discrete optical signal routers including a discrete 1x1 optical switch. The 1xM optical signal router can also be built using M 1x1 optical switches and an optical splitter integrated on a single optical substrate.

Equivalents

[0157] While the invention has been particularly shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. An optical signal router comprising:

a) a switch driver that generates at an output a modulation drive signal comprising a linear combination of a DC offset voltage and at least three electrical signals, each of the at least three electrical signals having a frequency that is a unique integral multiple of a bit-rate; and

b) an optical switch having an electrical modulation input that is electrically coupled to the output of the switch driver and having an optical input that receives a time-division multiplexed optical signal comprising a plurality of optical subchannels, each of the plurality of optical subchannels having the bit-rate,

wherein the optical switch routes a subset of the plurality of optical subchannels to an optical output of the optical switch in response to the modulation drive signal.

2. The optical signal router of claim 1 wherein the switch driver comprises:

a) a plurality of electrical signal generators, each of the plurality of electrical signal generators generating at least one of the at least three electrical signals; and

b) a signal combiner that combines the at least three electrical signals to generate the modulation drive signal.

3. The optical signal router of claim 2 further comprising an adjustable DC voltage source that generates the DC offset voltage.

4. The optical signal router of claim 1 wherein the switch driver is adapted so that at least one of an amplitude and a phase of at least one of the at least three electrical signals is adjustable.

5. The optical signal router of claim 1 wherein the optical switch routes the subset of the plurality of optical subchannels to the optical output of the optical switch in response to at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals.

6. The optical signal router of claim 1 further comprising an optical signal generator that generates the time-division multiplexed optical signal comprising a plurality of optical subchannels.

7. The optical signal router of claim 6 wherein the optical signal generator generates a polarization-multiplexed, time-division multiplexed optical signal.

8. The optical signal router of claim 6 wherein the optical signal generator generates a wavelength-division multiplexed, time-division multiplexed optical signal.

9. The optical signal router of claim 6 wherein the optical signal generator generates at least one of a wavelength-division multiplexed, time-division multiplexed, and polarization-multiplexed optical signal.

10. The optical signal router of claim 1 wherein a number of the at least three electrical modulation signals is less than a number of optical subchannels comprising the plurality of optical subchannels.

11. The optical signal router of claim 1 wherein a frequency of each of the least three electrical signals is lower than an aggregate bit rate of the time-division multiplexed optical signal.

12. The optical signal router of claim 1 wherein the optical switch comprises an interferometric switch.

13. The optical signal router of claim 1 wherein the optical switch comprises a Mach-Zehnder interferometric switch.

14. The optical signal router of claim 1 wherein the optical switch comprises a polarization-insensitive optical switch.

15. The optical signal router of claim 1 wherein the optical switch comprises an optical absorption switch.

16. The optical signal router of claim 1 wherein an aggregate bit rate of the time-division multiplexed optical signal is equal to or greater than ten gigabits per second.

17. The optical signal router of claim 1 wherein an aggregate bit rate of the time-division multiplexed optical signal is equal to or greater than eighty gigabits per second.

18. The optical signal router of claim 1 wherein the plurality of optical subchannels comprises at least four optical subchannels.

19. The optical signal router of claim 1 wherein the plurality of optical subchannels comprises at least eight optical subchannels.

20. A method for routing optical signals, the method comprising:

a) receiving a time-division multiplexed optical signal comprising a plurality of optical subchannels, each of the plurality of optical subchannels having a bit-rate;

b) generating a modulation drive signal that selects a subset of the plurality of optical subchannels, the modulation drive signal comprising a linear combination of a DC offset voltage and at least three electrical signals, each of the at least three electrical signals having a frequency that is a unique integral multiple of the bit-rate; and

c) modulating the time-division multiplexed optical signal comprising a

plurality of optical subchannels with the modulation drive signal, thereby selecting the subset of the plurality of optical subchannels.

21. The method of claim 20 wherein the selecting the subset of the plurality of optical signals comprises routing the subset of the plurality of optical signals along a first optical path and routing a complementary subset of the plurality of optical subchannels along a second optical path.

22. The method of claim 20 wherein the selecting the subset of the plurality of optical signals comprises routing the subset of the plurality of optical signals along an optical path and dropping a complementary subset of the plurality of optical subchannels.

23. The method of claim 20 wherein generating the modulation drive signal that selects a subset of the plurality of optical subchannels comprises varying at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals.

24. The method of claim 20 further comprising selecting another subset of the plurality of optical subchannels by changing at least one of the DC offset voltage, an amplitude of at least one of the at least three electrical signals, and a phase of at least one of the at least three electrical signals.

25. The method of claim 20 wherein the selecting the subset of the plurality of optical subchannels is performed within one microsecond.

26. The method of claim 20 wherein the selecting the subset of the plurality of optical subchannels is performed within ten nanoseconds.

27. The method of claim 20 further comprising generating the time-division multiplexed optical signal comprising a plurality of optical subchannels.

28. The method of claim 20 wherein the time-division multiplexed optical signal having a plurality of optical subchannels comprises a polarization-multiplexed time-division multiplexed optical signal.

29. The method of claim 20 wherein the time-division multiplexed optical signal having a plurality of optical subchannels comprises a wavelength-division multiplexed time-division multiplexed optical signal.

30. The method of claim 20 wherein the time-division multiplexed optical signal having a plurality of optical subchannels comprises at least one of a wavelength-division multiplexed, time-division multiplexed, and polarization-multiplexed optical signal.

31. The method of claim 20 wherein the number of the at least three electrical signals is less than the number of optical subchannels comprising the plurality of optical subchannels.

32. The method of claim 20 wherein a frequency of each of the at least three electrical signals is lower than an aggregate bit rate of the time-division multiplexed optical signal.

33. The method of claim 20 wherein an aggregate bit rate of the time-division multiplexed optical signal is at least ten gigabits per second.

34. The method of claim 20 wherein the plurality of optical subchannels comprises at least four optical subchannels.

35. The method of claim 20 wherein the plurality of optical subchannels comprises at least eight optical subchannels.

36. A method for routing optical signals, the method comprising:

a) means for generating a time-division multiplexed optical signal

comprising a plurality of optical subchannels, wherein each of the plurality of optical subchannels has a bit-rate;

b) means for generating a modulation drive signal comprising a linear combination of a DC offset voltage and at least three electrical signals, each of the at least three electrical signals having a frequency that is a unique integral multiple of the bit-rate, the modulation drive signal selecting a subset of the plurality of optical subchannels; and

c) means for modulating the time-division multiplexed optical signal comprising a plurality of optical subchannels with the modulation drive signal, thereby selecting the subset of the plurality of optical subchannels.

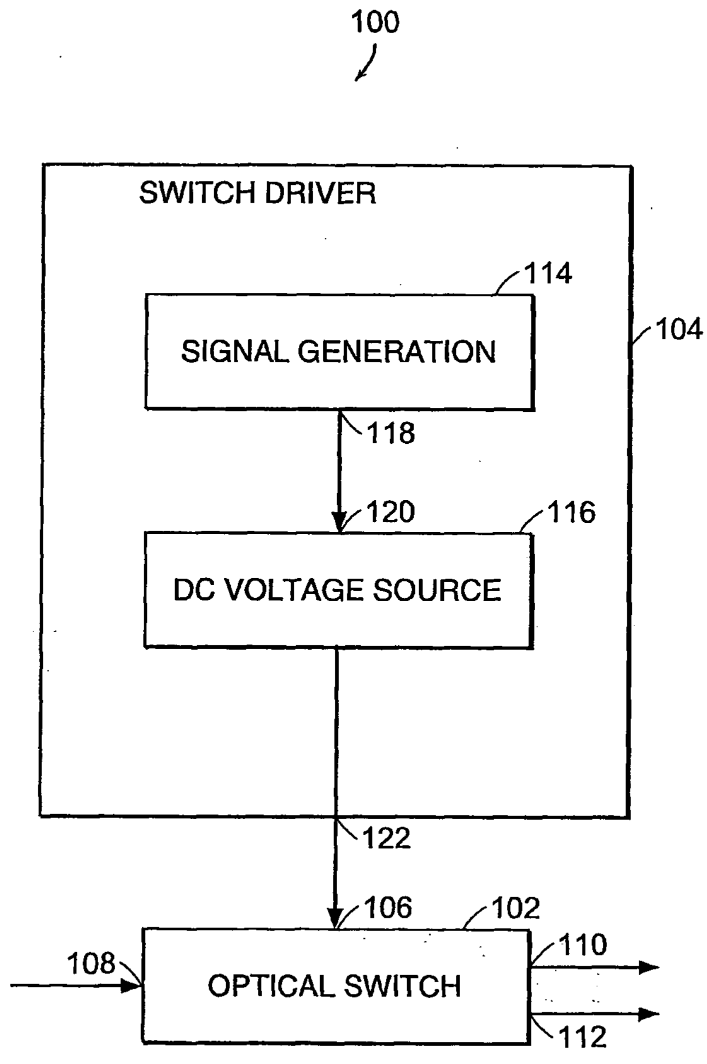

100
SWITCH DRIVER
114
SIGNAL GENERATION
104
118
120
116
DC VOLTAGE SOURCE
122
106
102
108
OPTICAL SWITCH
110
112

FIG. 1

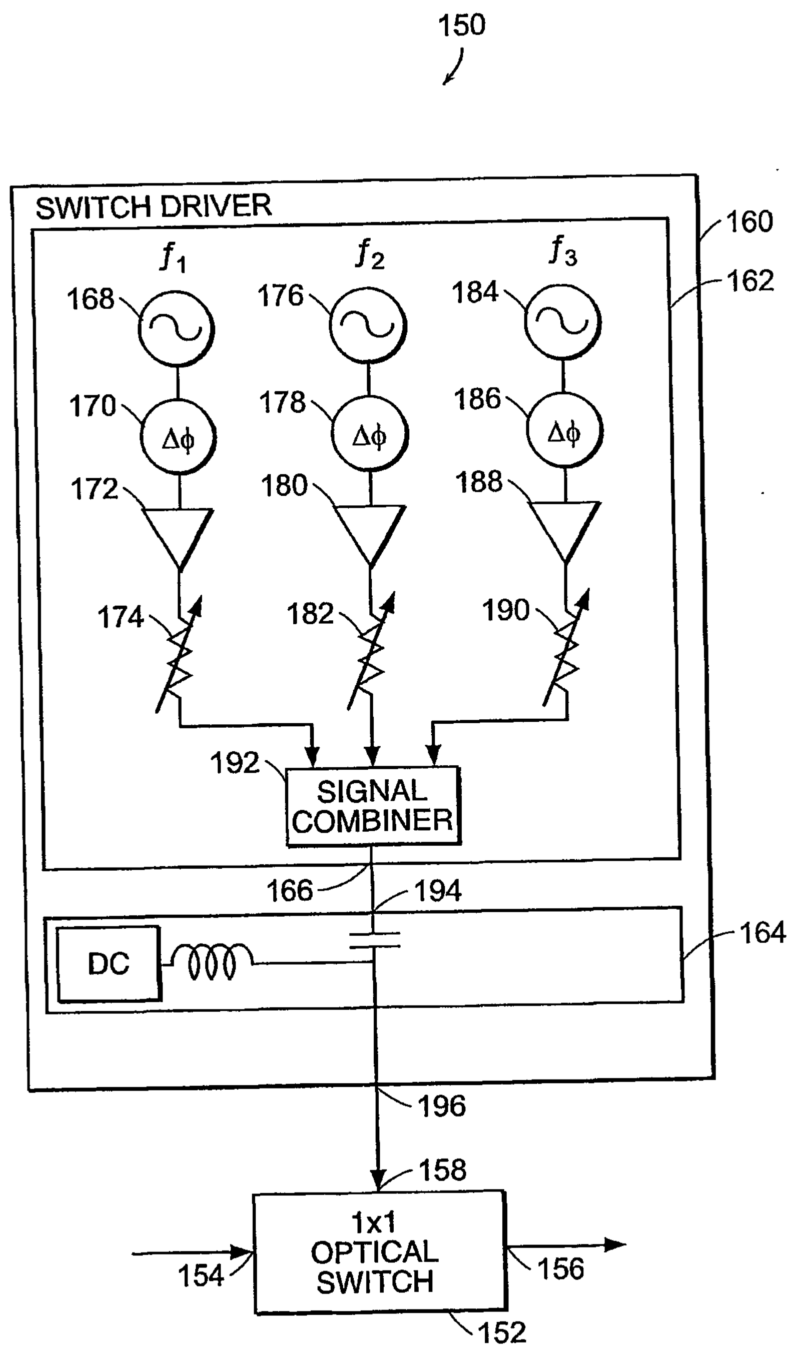

150
SWITCH DRIVER
160
162
f_1
f_2
f_3
168
176
184
170
178
186
Δφ
Δφ
Δφ
172
180
188
174
182
190
192
SIGNAL COMBINER
166
194
164
DC
196
158
1x1 OPTICAL SWITCH
154
156
152

FIG. 2

OPTICAL SIGNAL ROUTER CONFIGURATIONS
1x1 OPTICAL SWITCH, 4 OPTICAL SUBCHANNELS

198

INPUT OPTICAL SUBCHANNEL LABELS:

1	2	3	4

200

	SUBCHANNELS TO OUTPUT				SUBCHANNELS DROPPED				
0 SUBCHANNELS TO OUTPUT	-	-	-	-	1	2	3	4	4 SUBCHANNELS DROPPED
1 SUBCHANNEL TO OUTPUT	1	-	-	-	-	2	3	4	3 SUBCHANNELS DROPPED
	-	2	-	-	1	-	3	4	
	-	-	3	-	1	2	-	4	
	-	-	-	4	1	2	3	-	
2 SUBCHANNELS TO OUTPUT	1	2	-	-	-	-	3	4	2 SUBCHANNELS DROPPED
	1	-	3	-	-	2	-	4	
	1	-	-	4	-	2	3	-	
	-	2	3	-	1	-	-	4	
	-	2	-	4	1	-	3	-	
	-	-	3	4	1	2	-	-	
3 SUBCHANNELS TO OUTPUT	1	2	3	-	-	-	-	4	1 SUBCHANNEL DROPPED
	1	2	-	4	-	-	3	-	
202	1	-	3	4	-	2	-	-	204
	-	2	3	4	1	-	-	-	
4 SUBCHANNELS TO OUTPUT	1	2	3	4	-	-	-	-	0 SUBCHANNELS DROPPED

FIG. 3

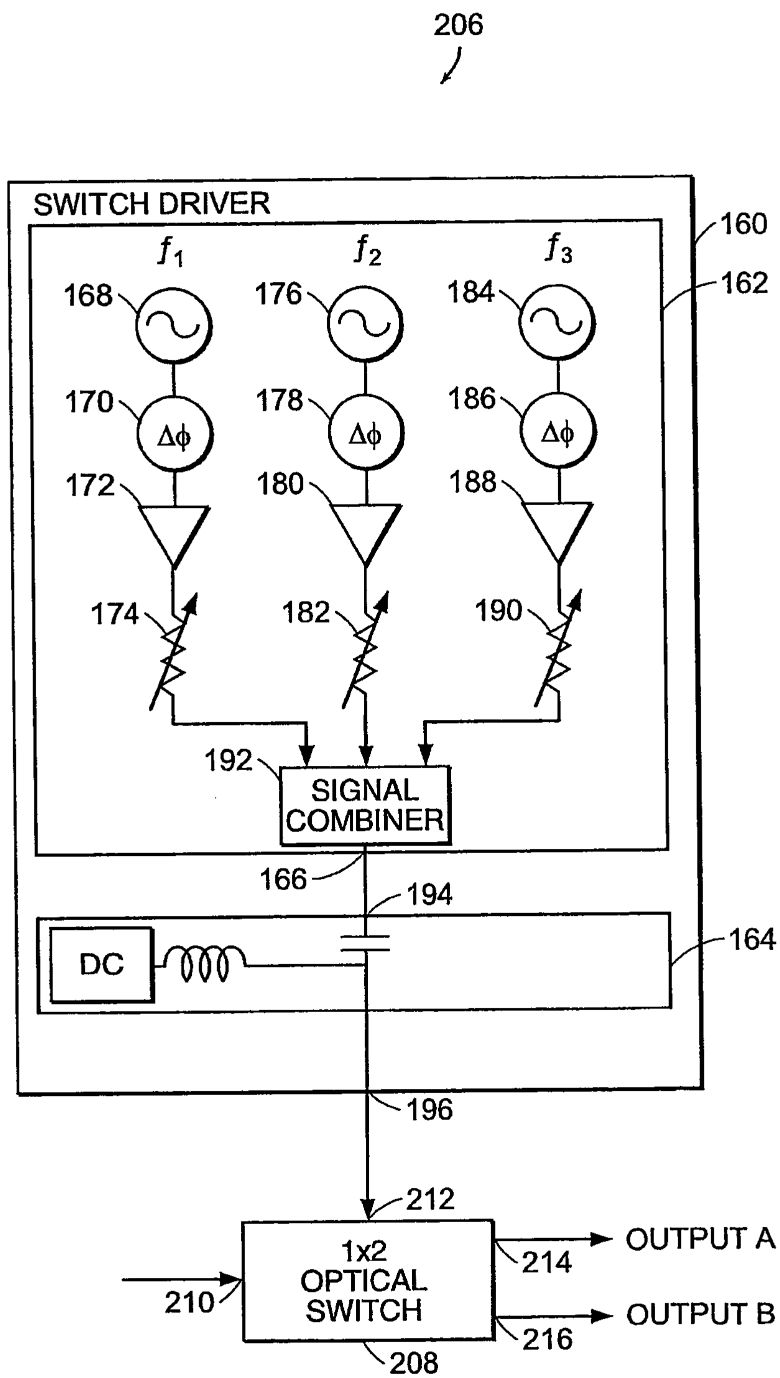

206
SWITCH DRIVER
160
162
f_1
f_2
f_3
168
176
184
170
178
186
Δφ
Δφ
Δφ
172
180
188
174
182
190
192
SIGNAL COMBINER
166
194
164
DC
196
212
1x2 OPTICAL SWITCH
210
214
216
208
OUTPUT A
OUTPUT B

FIG. 4

OPTICAL SIGNAL ROUTER CONFIGURATIONS
1x2 OPTICAL SWITCH, 4 OPTICAL SUBCHANNELS 218

INPUT OPTICAL SUBCHANNEL LABELS:

1	2	3	4	220

	SUBCHANNELS TO OUTPUT A				SUBCHANNELS TO OUTPUT B				
0 SUBCHANNELS TO A	-	-	-	-	1	2	3	4	4 SUBCHANNELS TO B
1 SUBCHANNEL TO A	1	-	-	-	-	2	3	4	3 SUBCHANNELS TO B
	-	2	-	-	1	-	3	4	
	-	-	3	-	1	2	-	4	
	-	-	-	4	1	2	3	-	
2 SUBCHANNELS TO A	1	2	-	-	-	-	3	4	2 SUBCHANNELS TO B
	1	-	3	-	-	2	-	4	
	1	-	-	4	-	2	3	-	
	-	2	3	-	1	-	-	4	
	-	2	-	4	1	-	3	-	
	-	-	3	4	1	2	-	-	
3 SUBCHANNELS TO A	1	2	3	-	-	-	-	4	1 SUBCHANNEL TO B
	1	2	-	4	-	-	3	-	
222	1	-	3	4	-	2	-	-	224
	-	2	3	4	1	-	-	-	
4 SUBCHANNELS TO A	1	2	3	4	-	-	-	-	0 SUBCHANNELS TO B

FIG. 5

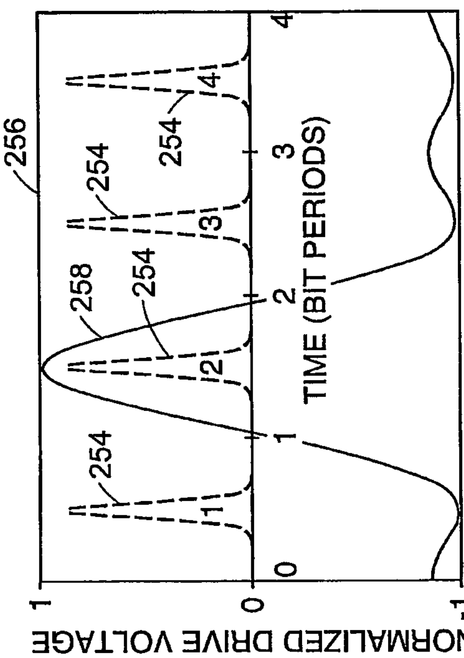


FIG. 6B

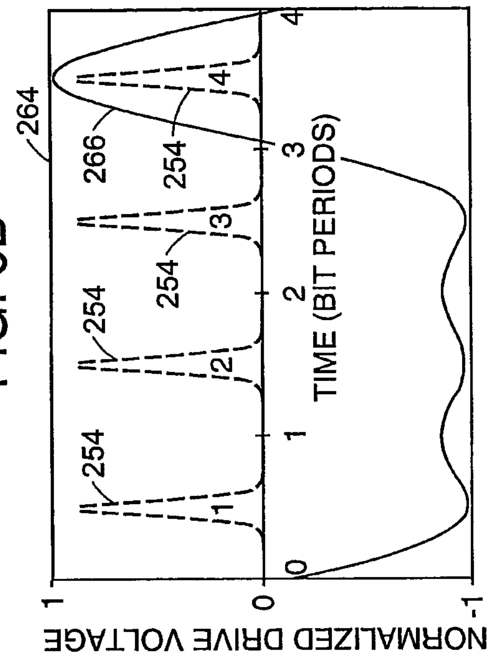


FIG. 6D

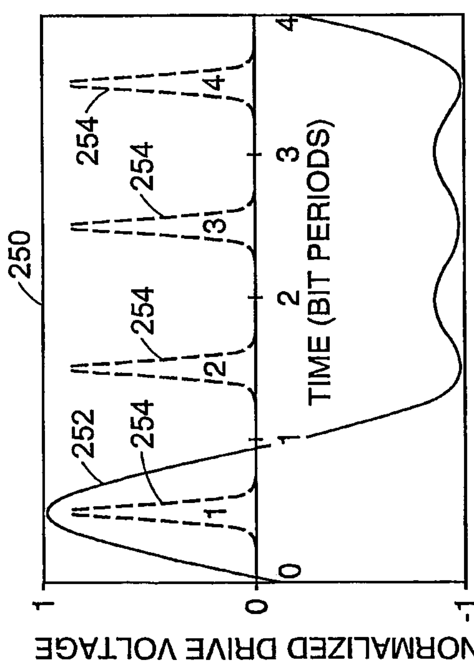


FIG. 6A

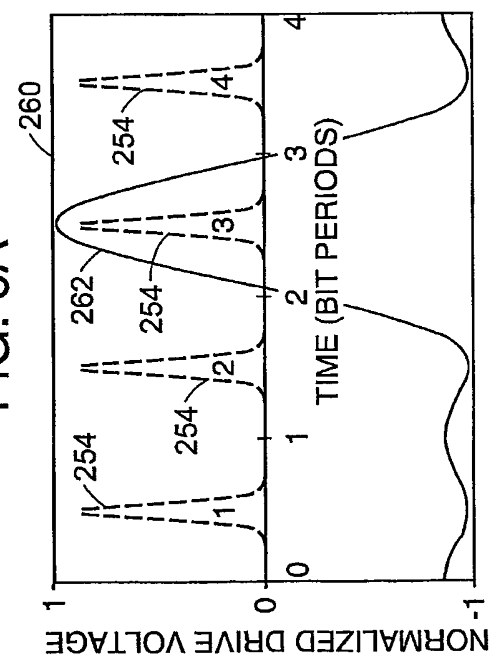


FIG. 6C

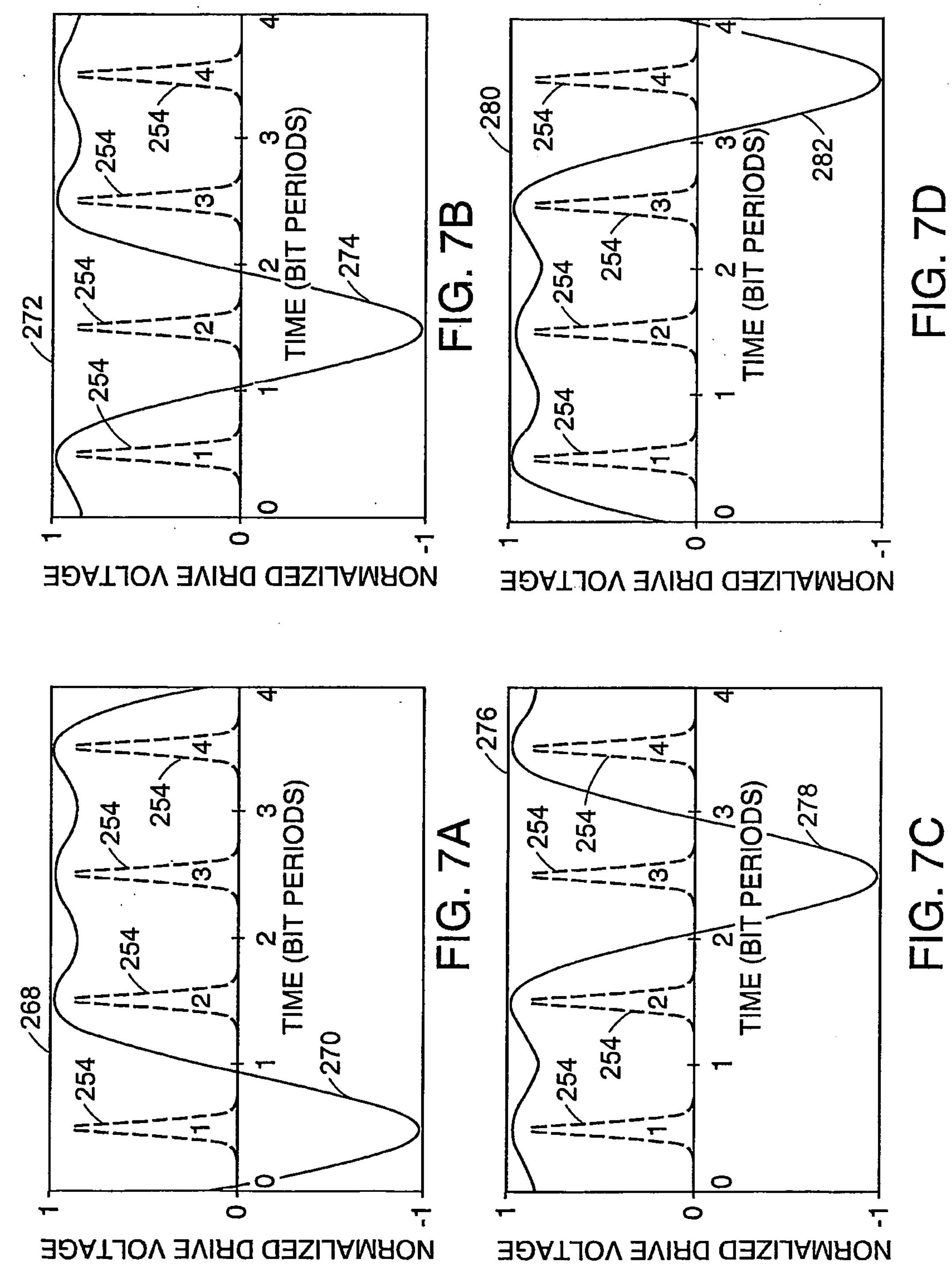


FIG. 7A

FIG. 7B

FIG. 7C

FIG. 7D

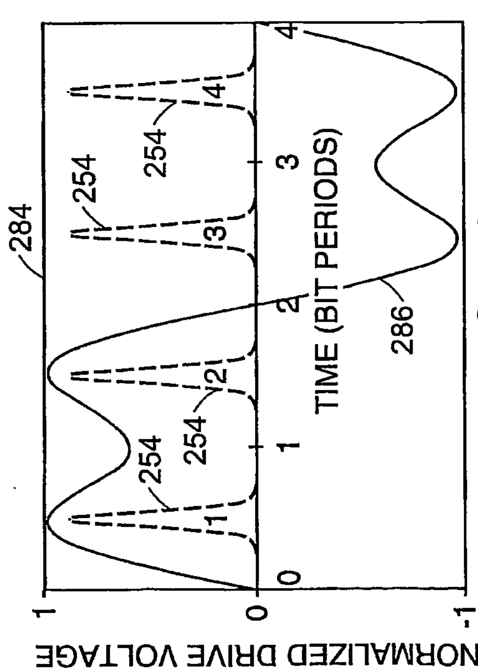


FIG. 8A

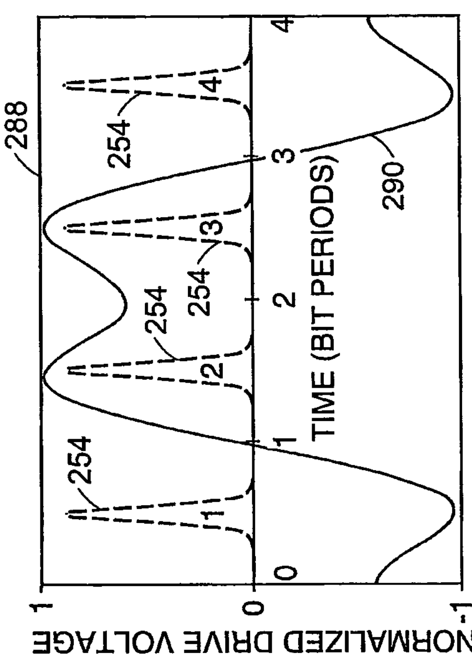


FIG. 8B

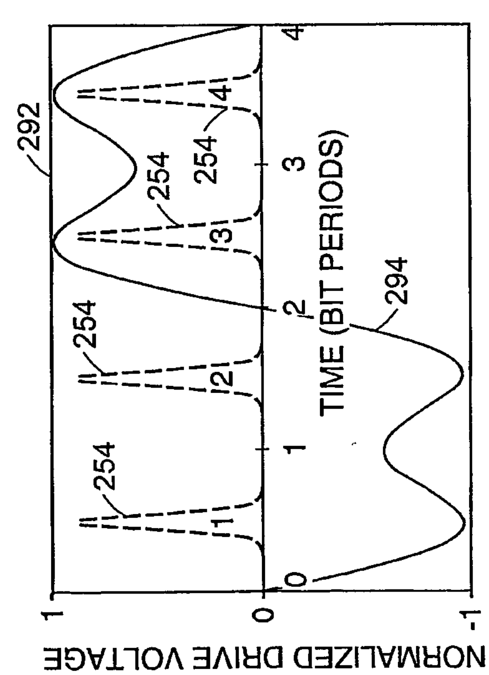


FIG. 8C

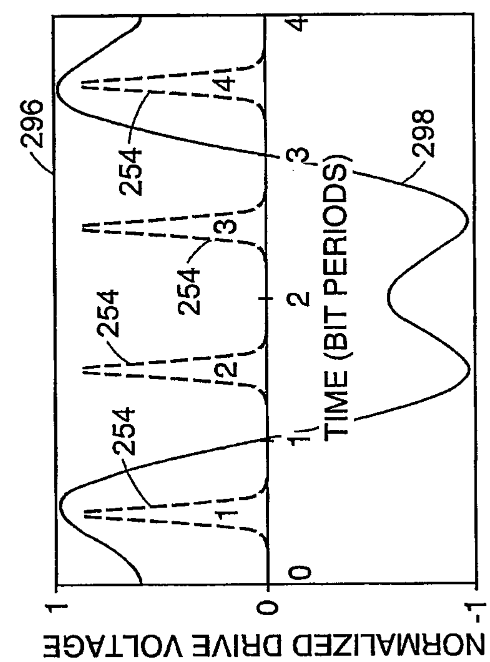


FIG. 8D

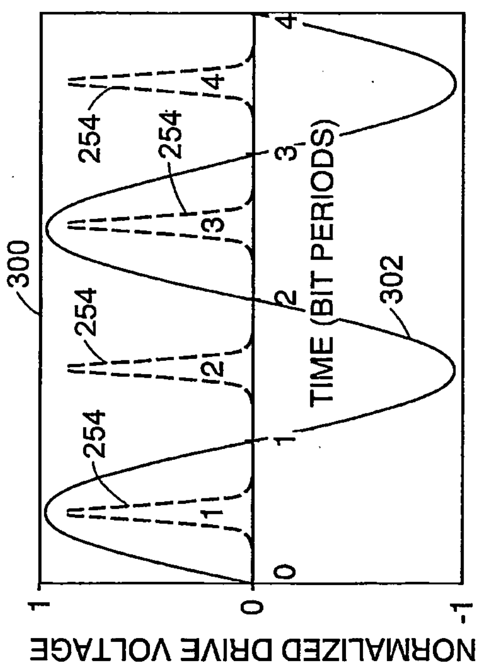


FIG. 9A

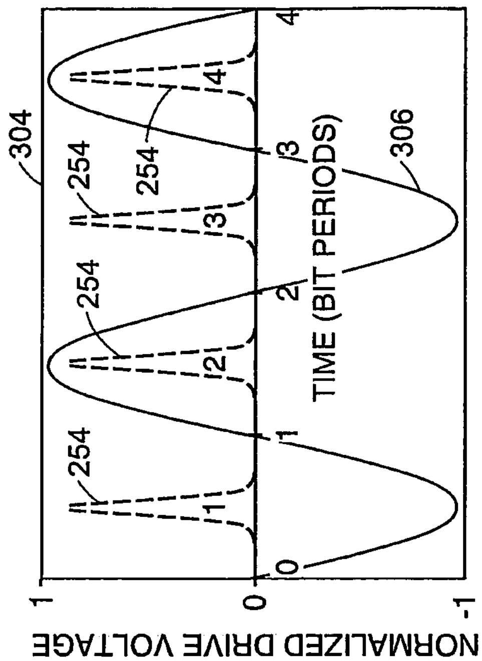


FIG. 9B

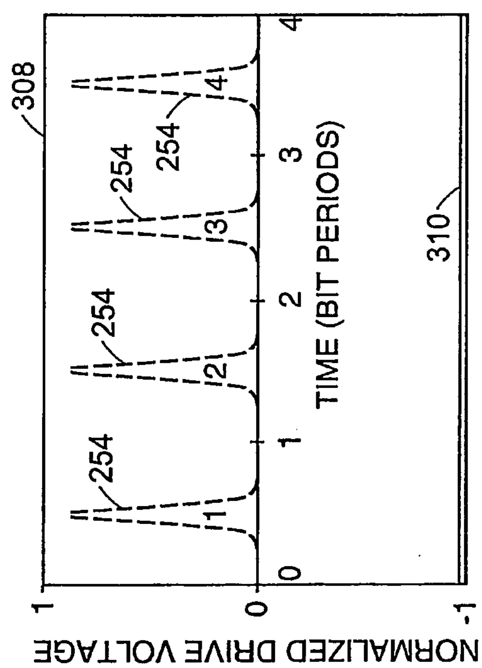


FIG. 10A

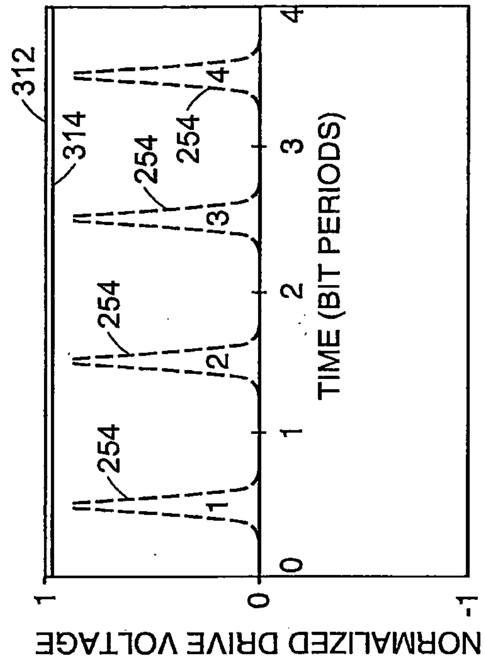


FIG. 10B

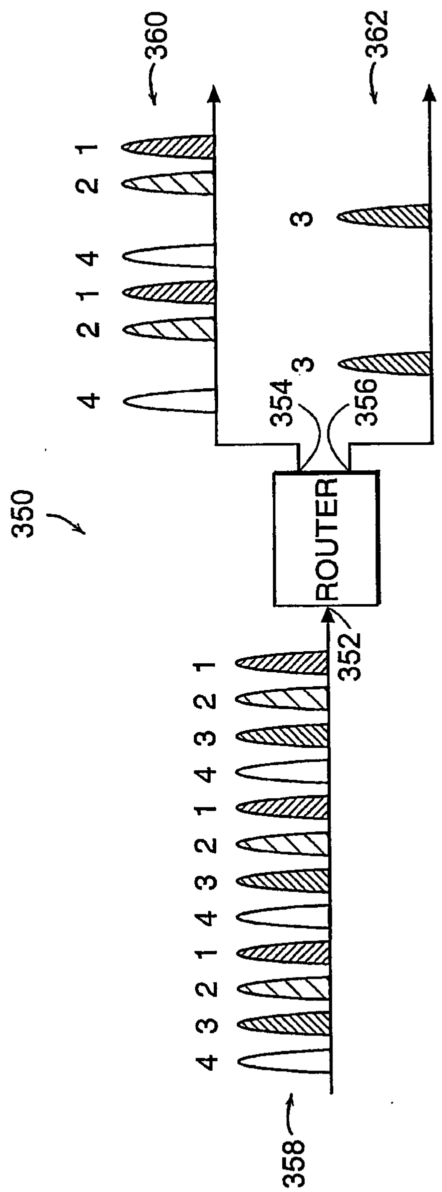

350
ROUTER
352
354
356
358
360
362

FIG. 11

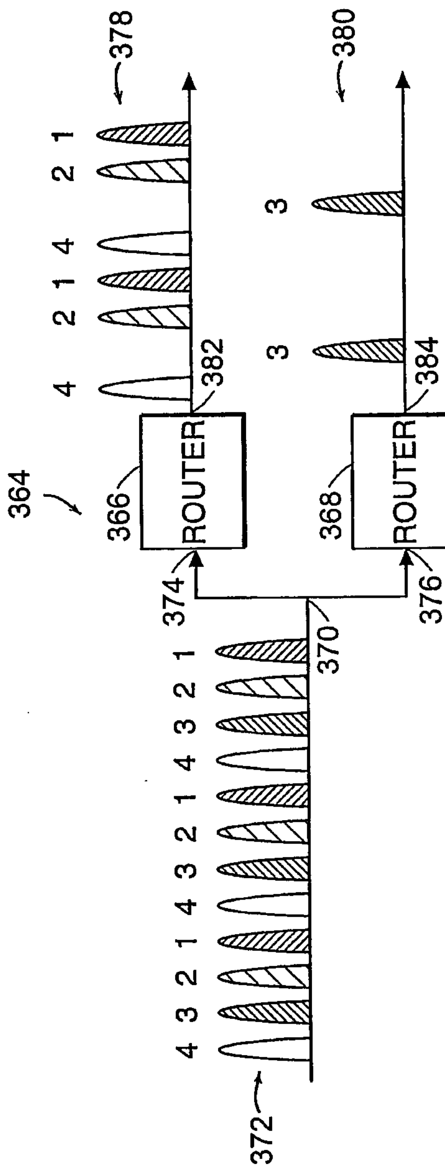

364
ROUTER
ROUTER
366
368
370
372
374
376
378
380
382
384

FIG. 12

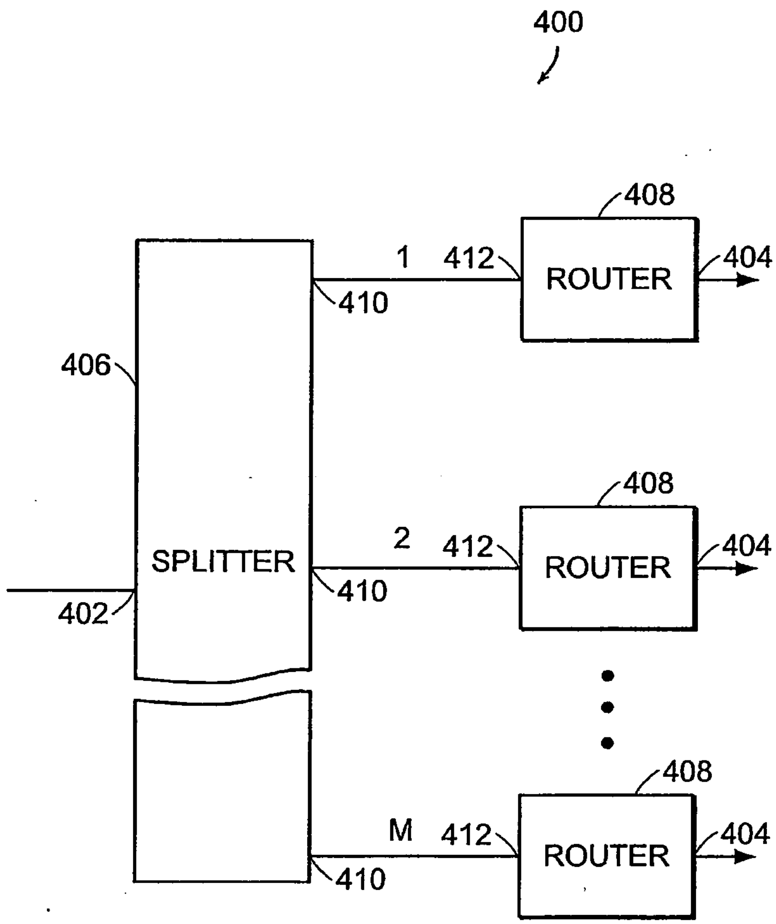

400
408
1
412
ROUTER
404
410
406
408
SPLITTER
2
412
ROUTER
404
402
410
408
M
412
ROUTER
404
410

FIG. 13

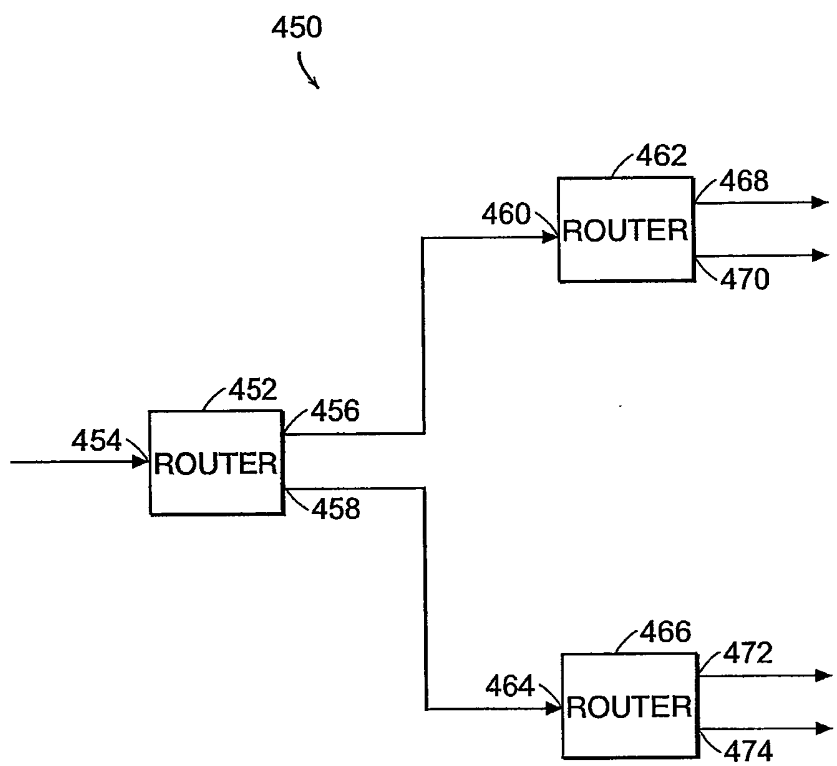

450
ROUTER
452
454
456
458
460
ROUTER
462
468
470
464
ROUTER
466
472
474

FIG. 14

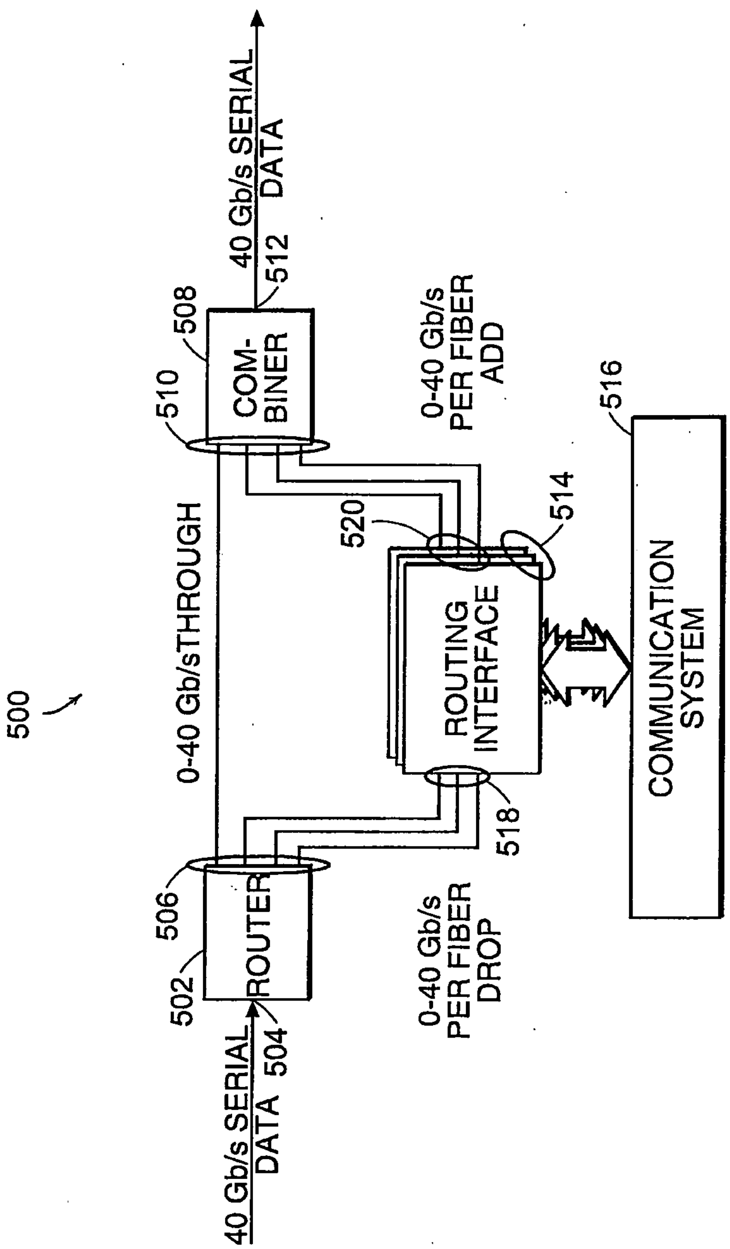

500
40 Gb/s SERIAL DATA
504
502
ROUTER
506
0-40 Gb/s PER FIBER DROP
518
0-40 Gb/sTHROUGH
ROUTING INTERFACE
520
514
510
COM-BINER
508
512
40 Gb/s SERIAL DATA
0-40 Gb/s PER FIBER ADD
516
COMMUNICATION SYSTEM

FIG. 15

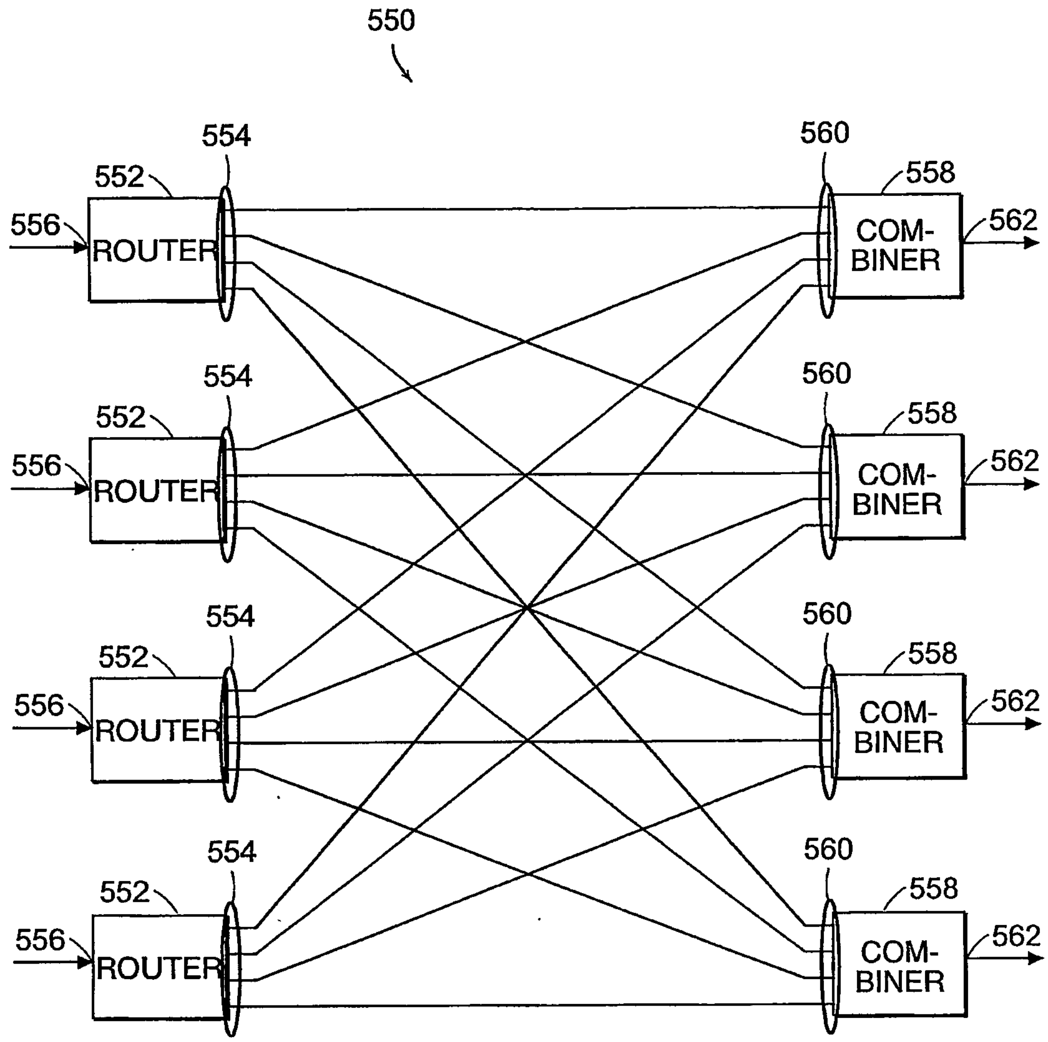

550
554
552
556
ROUTER
554
552
556
ROUTER
554
552
556
ROUTER
554
552
556
ROUTER
560
558
COM-
BINER
562
560
558
COM-
BINER
562
560
558
COM-
BINER
562
560
558
COM-
BINER
562

FIG. 16